# Validation of a Game Based Rehabilitation Platform for Assessment of Mobility and Cognitive Decline with Age

by

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# Abstract

The present study validates the Treadmill Rehabilitation Platform (TRP) protocol that assessed standing balance performance; spatial and temporal gait variability; stability measures and visual spatial cognitive task performances. Healthy individuals (mean age = 61.4± 4.4 years; n = 30) performed tasks from the TRP protocol while standing and while walking on treadmill. Moderate to High test retest reliability was observed for the TRP tool measures with a few exceptions. Standing balance decreased significantly as visual task load increased. Spatial and temporal gait variability increased whereas walking stability decreased significantly as visual task load increased. Visual task performance decreased significantly as physical load increased. In conclusion, the TRP protocol allows us to assess the ability to prioritize the division of attention when visual spatial cognitive tasks are performed while standing and during walking. Also**,** it allows reliable assessment of the effects of compromised attention during the tasks performances.

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# Dedication

I would dedicate my thesis to my family whose constant support kept me going and my wife, Anuprita Kanitkar whose love and support always encouraged me to achieve my dreams and made me believe in myself.

**Vedant Sakhalkar**

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## List of Abbreviations

AP: Antero Posterior

ADL: Activities of Daily Living.

ACE-R: Addenbrooke’s Cognitive Examination.

ANOVA: Analysis of Variance

AD: Alzheimer’s disease

BOS: Base of Support

COM: Center of Mass

CNS: Central Nervous System

COD: Coefficient of determination

COG: Center of Gravity

COP: Center of Pressure

CV: Coefficient of Variation

CTSIB: Clinical Test of Sensory Interaction and Balance

CHAMPS: Community Healthy Activities Model Program for seniors

DT: Dual-Task

df: Degrees of Freedom

EF: Executive Functions

FSA: Force Sensory Array

ICC: Intra-class Correlation coefficient

IMU: Inertial Measurement Unit

LOB: Loss of Balance

ML: Medio lateral

MIS-T: Memory Impairment Screening by Telephone

MMSE: Mini Mental Status Examination

MoCA: Montreal Cognitive Assessment

MCI: Mild Cognitive Impairment

MCTSIB: Modified Community Healthy Activities Model Program for seniors

MDC: Minimal Detectible Change

PWS: Preferred Walking Speed

RMS: Root Mean Square

RMANOVA: Repeated Measures Analysis of Variance

RT: Reaction Time

SD: Standard Deviation

SOT: Sensory Organization Test

SEM: Standard Error of Measurement

SST: Single Support Time

TRP: Treadmill Rehabilitation Platform

TICS: Telephone Instrument for Cognitive Status

TMT: Trail Making Test

TUG: Timed Up and Go

TEM: Technical Error Measurement

## Chapter 1: Introduction

The aging of our society has become one of the most important aspects of health care in the 21st century, as older adults are at high risk of cumulative chronic illness (cardiac, musculo-skeletal and neural) and vulnerable to the negative effects of increasingly sedentary lifestyle. In the later years of life, good balance and mobility skills are required to avoid physical dependence, fall injuries, hospitalization and even death. Studies have shown that one in three community-dwelling persons over 65 years of age experience a fall at least once a year and over 50% of falls in older persons occur during walking (Verghese et al., 2006; 2008; Shin et al., 2009). The decline in mobility skills and occurrence of falls may occur due to a single event like stroke, traumatic brain injury or even it may result due to the contribution of various other neurological deficits. These factors contribute to restriction in ability to participate in family and community life. As an example, decline in balance and mobility results in increased fall risk and are prognostic of future adverse health events. Many studies have used balance performances and gait outcome measures to assess health status, quality of life and physical functions in older adults.

The decline in the ability of mental processing is considered to be an early marker of dementia, and the decline in ability of executive processing associated with mobility limitations also result in increased risk of falling (Verghese et al., 2006; Springer., et al 2006; Grabiner and Troy., 2005; Kelly et al., 2008). Many researchers are examining the interaction between mobility and cognitive functions using a Dual-Task paradigm. A computer game based rehabilitation platform, for assessment and intervention has been developed to examine both mobility and cognitive impairments. A computer monitoring system and interface is used that allows balance and walking tasks to be coupled with a variety of concurrent visual spatial cognitive tasks (i.e. Dual-Tasks).

## Chapter 2: Review of Literature

### *2.1 Balance and Aging*

Balance is defined as the ability to maintain position and motion of total body center of mass with respect to the base of support. In general, there are three neural processes that are considered to regulate stability; 1) Sensory Receptor System that provides information about body orientation, motion and external spatial cues; 2) Components of the central nervous system (CNS) responsible for organization and integration of different types of spatial cues provided by visual, somatosensory and vestibular systems; 3) Motor centers which are responsible for selection and execution of goal oriented compensatory reactions or adjustments. The motor aspect of balance control includes feedback and feed forward control mechanisms. The feed forward mechanism is a predictive, preparatory postural response to expected or anticipated threat to balance. The feedback mechanism is an automatic balance reaction to an unexpected stumble.

Environmental conditions such as nature of the support surface and the surroundings along with the demands of the task determine the stability requirements. The nature of the support surface can be firm, uneven, compliant or slippery. Surroundings may consist of moving objects or crowded areas (Maki et al., 1990, Balasubranian et al., 2000; Shum-way-Cook and Horak., 1986). In an attempt to avoid obstructions and overcome challenges, the balance control system requires proper processing of spatial sensory information (Horak et al., 1996). The concept of use of balance control network for regulation of standing balance needs, are significant as multilink complex synergies are necessary to restore balance and sensory processing is required to determine the threat to balance.

Several laboratory tests to assess balance control system using the sensory inputs from visual, somatosensory and vestibular sensors have been developed. Nashner et al (1971), developed a test protocol called, the Sensory Organization Test (SOT). The purpose was to measure the contribution of different sources of spatial information provided by each sensor. This test was further commercialized and named the “Equi-test” (Petreka and Black., 1990). The SOT consists of six sensory balance tests during which COP movements are recorded. The magnitude of COP excursion is used to index standing balance performance from a basic task of maintaining an upright stance. The following six tasks were used in the SOT:

1. Standing with eyes open on a fixed surface; in this condition all spatial sensory information from vestibular, somatosensory and visual sensors is available.
2. Standing with eyes closed on a fixed surface; in this condition the visual signals are eliminated.
3. Standing on fixed surface with visual surround that sways proportionately to body sway; in this condition, the visual surround moves proportionately to body sway. Thus there is no motion of head relative to visual surround. There is no relative difference between body movement and visual surround. This is referred to as visual referenced condition in which the body sways but vision is unable to detect this sway.
4. Sway referenced support surface similar to vision referenced condition. In this condition the support surface on which the person is standing moves in synchrony and in

proportion with body sway, (i.e. COP signal). This effectively cancels out the motor and somatosensory signals of ankle motion.

5. Sway referenced support surface with eyes closed: in this condition, the somatosensory inputs from ankles are eliminated or distorted along with the vision being eliminated,

6. Sway referenced and vision referenced condition together. Both somatosensory and visual spatial information are eliminated or distorted.

Nashner et al., (1981) used the SOT to assess 12 participants with vestibular dysfunction and observed that, in conditions 1 to 3, where the support surface was fixed relative to earth horizontal, all participants were able to orientate themselves vertically, similar to normal. In condition 4, the support surface was sway referenced making it difficult to derive somatosensory information from the ankles, which results in greater weighting of vestibular and visual inputs. In condition 5, when the eyes were closed and visual cues were absent while standing on the sway referenced platform, sway was observed to be substantially increased. In condition 6, when both ankle and visual inputs were eliminated or distorted, more sway was noted in all participants and several lost their balance. Inaccurate visual and somatosensory information resulting from loss of relative motion signals between the ankles and the environment caused sensory conflict situations. Consequently, errors were made in sensing vertical body sway increased. Healthy young adults and participants with vestibular deficits were able to maintain their balance with increased sway. By eliminating or distorting one sense at a time, this study demonstrated how sensory inputs could be manipulated resulting in greater reliance on other senses. As the balance task became harder by the elimination or distortion of vision and alteration of somatosensory inputs, greater reliance was placed on vestibular inputs.

As long as reliable inputs regarding earth vertical or earth horizontal were available, balance was maintained. However, as the balance tasks became harder and visual and somatosensory distortions were introduced, there was a greater likelihood of balance loss and falls. Furthermore, participants with greater vestibular loss had more difficulty in managing to determine their state of balance under the varied sensory conditions. Balance can be maintained if there is loss or distortion of only one of the sensory systems, but becomes challenged or impossible when more than one is absent or becomes unreliable (Desai et al., 2010).

Different studies have used the SOT to evaluate balance control in elderly participants. Whipple et al., (1993) used SOT conditions to assess standing balance. They compared 239 healthy elderly participants (mean age of 76.5 years) and with independent ambulation and no neurological deficits to 34 young healthy adults (mean age 35 years). A significant age effect was observed for condition 4 (which is eyes open, sway stabilized) and condition 5 and 6 (which is eyes closed, sway stabilized and inaccurate vision, surface movement respectively). Thirty two percent of the older adult group lost balance on condition 5 where as 52% on condition 6. In comparison, only 6% of younger adults lost balance during condition 5 and 9% on condition 6. To conclude the author stated that the unstable platform condition was more challenging for both the participant groups. But the older adults showed a substantial drop in performance when vision was eliminated. Hence for the assessment of balance control not only the support surface condition is important but also visual information plays a crucial role.

A study by Cohen et al., (1996) assessed standing balance of 94 community dwelling participants using conditions of the SOT. Participants were divided into four groups; 1) 32 young adults (18 to 44 years of age), 2) 30 middle aged (45 to 69 years of age), 3) 19 old aged (70 to 79 years of age), 4) 13 elderly (80 to 89 years of age). A statistically significant age effect was observed on sensory conditions 4 through 6. No significant difference in SOT performance scores was observed between young and middle aged groups on conditions 3 and 4. A moderate difference was seen on conditions 5 and 6. Not much age difference was observed in old and elderly aged groups on conditions 1 through 4, except for conditions 5 and 6. On condition 5, 70% falls in elderly were seen but only 30% in old aged participants. On condition 6, 100% loss of balance in elderly, 30 % in old and young aged group; and 10 % in middle aged group was seen. These findings are similar to the findings of Whipple et al., (1996).

Shumway- Cook and Horak., (1986) developed a simpler and inexpensive version of the SOT. They called it the Clinical Test of Sensory Interaction and Balance (CTSIB). Instead of using a sway referenced platform, a sponge was used to distort the signals coming from the ground. One of the benefits of using foam over the SOT is that the sway referencing of the surface is not limited to the pitch plane but it can be sway referenced in almost all directions. The compliant sponge surface alters the ground reaction forces under the feet (Blackburn., 2003, Peterson et al., 2008). Two methods were used to grade this clinical test: 1) Ranking system, that is by the use of a four point ordinal scale, (1- minimal sway, 2- mild sway, 3- moderate sway, and 4- fall); 2) use of a stop watch to record the amount of time taken by patient to maintain balance to a maximum of 30 seconds. The CTSIB is easy and inexpensive to reproduce within clinical settings. Many studies demonstrate body sway increases significantly when standing on a compliant sponge surface, as compared to a normal, fixed floor surface (Teasdale et al., 1991, El Kashlan et al., 1998; Kuo et al., 1998, Blackburn et al., 2003, Creath et al., 2005).

Lord et al., (1994) examined postural sway in twenty five participants (10 men and 15 women with mean age 67.1 ± 7.6 years). Participants were grouped into two different groups: one with diabetes but had no neurological deficits and other had normal participants with no diagnosis of diabetes and neurological deficits. All the participants had to perform two tasks of eyes open and eyes closed on firm and compliant sponge surface conditions. The total sway was measured for 30 seconds using a sway meter. They observed that the performance of the participants with diabetes decreased during all the conditions. The performance of the control group participants decreased only during eyes closed compliant sponge surface condition. The overall performance of the participants with diabetes was significantly lower than the control group participants.

Abrahamova et al., (2008) examined age related changes in COP parameters of quiet stance under four conditions. Eighty-one healthy participants were recruited for the study. They were divided into three groups; 1) 34 juniors: 20 to 40 years of age; 2) 20 middle-aged: 40 to 60 years of age; 3) 27 seniors: 60 to 82 years of age. They used conditions of the CTSIB and a custom made force platform to record the COP displacement in antero-posterior (AP) and medio-lateral (ML) directions. They considered total amplitude and velocity of COP excursion in AP and ML directions. Root Mean Square (RMS) and total area of COP displacement was also calculated. They observed increase in COP displacement relating to age and in conditions with alteration of sensory information. These findings are similar to that of the SOT where condition 5 and 6 results in considerable increase in sway and often results in loss of balance (LOB).

A study done by Allum et al., (2003), used a compliant sponge support surface to distort the sensory input similar to the sway referencing conditions of SOT.

Strang et al., (2011) assessed postural sway using COP displacement variables of path length, area of displacement, sample entropy and normalized path length during two conditions of eyes open and closed while standing on firm and compliant surfaces. They included 26 participants (7 men with mean age of 21.4 ±0.20 years and 19 women with mean age 20.74±0.18 years) with no history of lower extremity injury within past six months and no balance disorders. Participants were asked to perform following tasks: standing on firm surface with eyes open; eyes closed; standing on foam surface with eyes open and eyes closed pre and post six weeks of balance training program. For the balance training program participants were asked to perform a set of nine high level balance training exercises. Center of Pressure movements in AP and ML directions during the eyes open and closed conditions on firm and compliant surfaces were recorded using a force plate (Bertec, USA). They reported following results: there was a significant increase in the area of COP movement and path length on compliant surface than on fixed surface; significant increase in COP movements during eyes closed condition than eyes open. They reported no effect of balance training program on the amount of postural sway.

Desai et al., (2010) performed a study to examine the use of the Dynamic Balance Assessment test (DBA) to differentiate fallers from non-fallers. They included 72 community dwelling individuals (aged 65 years and above) in the study. Participants were asked to perform 6 tasks; 1) quiet standing on a firm surface with eyes open; 2) standing on firm surface with eyes closed; 3) standing on firm surface while performing cyclic, horizontal head rotations to visual targets placed 120 degrees apart; 4) standing while performing a cyclic, arm lifting task; 5) performing cyclic, rhythmic horizontal trunk rotations to 45 degrees in each directions; 6) standing while performing cyclic, rhythmic forward trunk bending and extension to return to the upright standing position. COP was recorded using a Force Sensory Array Mat (FSA) (Vista Medical Ltd, Winnipeg, MB), and peak to peak excursions and total sway path length in AP and ML directions were used to measure the performance. There was a significant increase in the COP excursions on the compliant surface during eyes closed and during trunk rotations and flexion extension movements. They observed that the COP displacements during the performance on sponge surface and not the normal fixed surface were able to predict falls. The study suggested that the analysis method used to assess the COP displacements during different tasks and under different surface conditions is an appropriate method to examine dynamic balance control. The study also concludes that the scores calculated from the 6 tasks were able to identify the fallers from non-fallers (Desai et al., 2010)

## *2.2 Summary of the Evidence on Balance Control*

Balance is considered to be a behavioral term and its normal control is a complex multi-dimensional process. An efficient way of assessing balance control in community dwelling adults is required. The assessment tools developed such as the SOT and other moving platforms are very expensive and require technicians to operate and maintain. The CTSIB on the other hand is easy to use but only considers time as the outcome measure. A number of studies have used a compliant sponge support surface to distort the sensory input instead of the sway referencing conditions of the SOT. Some studies use body sway as their outcome measure but it requires attachment of sensors onto the body segment. Some studies that used force pressure sensors to evaluate stability by using COP displacement under compliant sponge conditions used sponge over the force plate. This way the body forces acting on the support surface get distorted by the compliant foam pad before they are detected resulting in misinterpretation of the data recorded. The use of a compliant sponge surface is efficient for sway referencing as it is not restricted to just one direction (as in SOT), that is the unpredictable rotation of the compliant surface can occur in all directions from antero-posterior to medio-lateral. Thus delayed spatial information from the sensors of feet and ankle will result in producing more challenge for maintenance of balance. To conclude, use of this surface along with the force mat can evaluate sensory and motor processes while maintaining balance control.

### *2.3 Mobility and Dual Tasking*

Community walking can be a complex behavior that involves considerable cognitive processing. During outdoor walking sensory, cognitive and motor processes are required to deal with various environmental challenges (Verghese et al., 2006). Executive functions (EF) being one of the requirements for mobility are observed to decline with age and due to these changes, safe walking in outdoor environments and busy surroundings becomes difficult (Herman et al., 2010; Yogev- Seligman et al., 2008; Van lersel et al., 2008, Coppin et al., 2006; Hausdroff et al., 2008). Cognitive demands of gait control can be examined using a dual-task paradigm, where, the interplay of walking and cognitive skills can be measured and analyzed (Abernethy., 1988). A dual-task paradigm is a procedure that requires an individual to perform two simultaneous tasks, in order to grade individual performances and to observe the interaction between the two tasks. Various studies on gait performances under dual tasking have put forth the affirmation that impairment in the ability to assign attention to individual tasks may contribute significantly to fall risks. Fall risk in the older population is increased by divided attention tasks especially in people with motor and cognitive impairments (Verghese et al., 2006; Hall et al., 2011). It is important to assess the frail population for fall risks before an incidence of disability or mobility impairment occurs.

### *2.4 Incidence and Prevalence of Mobility Limitations*

A study conducted by Verghese et al., (2006), examined the incidence of gait disorders and its association with the risk of hospitalization and death in 488 older adults (70 to 90 years of age). The study uses a classification of gait pattern by visual observation, as the participants performed following tasks: walked up and down a well-lit hallway at their preferred speed; tandem gait; and walking with making turns. Gait pattern was categorized into abnormal and normal. Abnormal gait patterns were further divided into neurological and non-neurological. The neurological gait abnormalities were considered as unsteady if the participants swayed more or lost balance during tandem walking or walking while making turns. They graded these abnormalities as mild, moderate or severe. Cognitive functions were assessed using neurological test battery that included; 1) Memory Impairment Screening by Telephone; 2) Telephone Instrument for Cognitive Status (TICS). They observed that 168 participants were diagnosed with abnormal gait, 70 with neurological, 81 with non-neurological and 17 with combined gait disorders. Unsteady gait type (46.6%) was most commonly observed subtype. Overall, the estimated prevalence of moderate to severe abnormalities in gait was higher for non-neurological gait abnormalities (33.3%) than for neurological gait abnormalities (17.1%). The prevalence rate for abnormal gait was 35%; for neurological gait 15.7% and for non-neurological gait disorders 20.8%. The prevalence rate for abnormal gait status was observed to be increased from 24.3% to 45.9% as the age increased from 70 to 90 years. The findings also suggested that participants with moderate to severe gait abnormalities were more prone to the risk of hospitalization and death, than those with mild abnormalities.

In a subsequent study Verghese et al., (2009) examined the association of stride length variability, swing time variability and double support time, gait speed with incidence of fall rate. They included 597 participants (mean age 80.5 years), for the study. Participants were asked to walk on the Gait Rite carpet and the gait variables were recorded from approximately 5 steps. They observed that a decrease in the gait speed was significantly associated with increased risk of falling. The association of injurious fall rate with a 10 cm/second decrease in gait speed was observed to be 7%. Swing time variability, stride length variability were highly associated with increased risk of falling.

Shin et al., (2009) performed a study to examine demographic data, cognitive status and activities of daily living (ADL) and its association with the risk of falling in 335 Korean community dwelling older adults (mean age 72.87 years). They conducted home interviews to record the demographic data of age, gender, education, income and marital status and history of diseases and medications. Cognitive status was assessed using Korean version of MMSE (Folstein et al., 1975). The Barthal index score was used to measure performances in the activities of daily living. They observed that approximately 15 % of the participants experienced a fall in the follow up period of one year. Falls were experienced due to slipping (52.1%), loss of balance (8.3%), tripped (6.3%) and while walking (6.3%). They observed that 52% of the falls amongst all the participants occurred during indoor walking where as 41.7% of falls occurred during outdoor walking. They also performed a chi square test and t test to observe the difference between fallers and non-fallers. There was no significant difference observed with respect to the demographic data and history of diseases and medications but, fallers had comparatively low exercise behavior and ADL. They also observed that participants who were even slightly less sedentary were 1.02 times less likely to be fallers.

Herman et al., (2010), examined gait speed, swing time variability during normal walking and walking while performing the Stroop test, Trail Making Test (TMT) A and B, verbal fluency, forward and backward digit span test and their association. They included 262 community dwelling healthy older adults (age ranging from 70 to 90 years) who reported no history of falls in the past year. Participants walked on 25 m long walkway and gait was assessed using force sensitivity insoles that determined gait speed and swing time variability. They observed that 42.3% of the participants experienced 168 falls during the 2 years of follow up period. The composite scores of the executive function (EF) task performances was lower among the participants who reported falls during 2 years of follow up than those who did not report any fall. They also observed that gait variability during dual tasking and the scores of Trail making Test- B were highly associated with future falls in the fallers than the non-fallers. This indicates that participants with decreased cognitive ability have difficulty in mobility.

### *2.5 Link between Mobility and Cognitive Skills*

In a study by Dubost et al., (2006), 45 older adults (mean age 65.3 years) were tested to examine the relationship between change in stride velocity and stride length during normal walking and walking while performing a verbal task of enumerating animals. Gait parameters of stride velocity and stride time variability were calculated. Mean and coefficient of variation (CV) for stride time, mean value of stride velocity were computed. Numbers of animals enumerated were determined but not the errors or wrong responses. They observed a strong association between variation in stride velocity ($r^2 = 0.9$), stride time variability ($r^2 = 0.8$) and verbal task performance.

McGough et al., (2011) examined the association between change in gait speed and executive function tests such as the Trail Making Test - B and Stroop test. They also examined the association between the Timed up and Go test (TUG) and the two executive function tests. They included 201 sedentary older adults with cognitive impairments. Cognitive assessment was performed using, 1) a telephone screening interview, and 2) a semi structured interview at the participant's home and neuropsychological screening tests. Participants were instructed to walk on an 8 foot hallway and the time taken to finish was used to calculate gait speed (meters per second). The Time taken to finish TUG was recorded and was log transformed for the analysis. They observed a moderately significant association between gait speed and the Trail Making test ($r^2 = 0.7$) and Stroop test ($r^2 = 0.5$). The TUG was observed to be strongly associated with Trail making Test ($r^2 = 0.8$) whereas moderately associated with the Stroop test ($r^2 = 0.6$). The findings suggest that slow walking speed and an increase in the time taken to finish TUG are associated with a decrease in the performance of the executive processes and they indicate risk of functional decline and disability.

Hall et al., (2011) examined the association between gait speed and performing concurrent cognitive tasks such as reciting alternate letters, verbal fluency task and counting task among a group of 77 participants (age 65 or above). Participants were asked to walk a distance of 6m at their preferred walking speed. The time taken to finish was recorded and gait speed (m/s) was calculated accordingly. They observed low association among the following variables: the decrease in gait speed and reciting consecutive alphabets ($r^2$= 0.339); 2) reciting alternate letters ($r^2$= 0.397); 3) counting ($r^2$= 0.358) and 4) verbal fluency task ($r^2$= 0.345). To conclude, the author suggests that gait demands attention and any concurrent task performance affects gait speed. The author also suggests that amongst four tasks, reciting alternate letters and verbal fluency affected gait speed more. It is also suggested that the more complex the cognitive task, the greater would be the impact on the performance of gait. This might be helpful in deciding tests to use in clinical settings. The change of speed during the dual-task condition with various cognitive tasks differed each time, which shows that for different dual-task conditions, the prioritization changes.

Whitney et al., (2012) performed a study to examine the association of cognitive processes, mobility skills and risk of falling in 109 older adults (age 60 years and more). Cognitive processing of attention, orientation and visual spatial abilities was assessed using Addenbrooke's Cognitive Examination (ACE-R). Language was assessed using the Boston naming test. Short and long term memory was assessed using the Wechsler Memory Scale 3. Trail Making Time was used to assess processing speed. Balance was assessed using the TUG test whereas gait speed was measured using the 6m distance walk. The physiological profile assessment was used to measure postural sway. They observed following results: 1) Among all the participants 49% experienced falls during the follow up period of 6 months. 2) Fallers showed a significant decrease in gait speed during dual tasking; 3) the performance in ACE-R scores was also significantly low. 4)

Fallers showed increased postural sway compared to non-fallers. 5) Cognitive processes of attention and orientation had a low association with the risk of falling (r = -0.27). 6) The association between the amount of postural sway during dual tasking and risk of falling was also observed to be low (r = 0.29). The results indicate that the cognitive tasks used in the study did not challenge cognitive ability as well as balance to a greater extent. Hence a good cognitive task that causes divided attention is important to assess dual-task ability.

Hollman et al., (2010) conducted a study to calculate the number of strides required to reliably measure three major gait parameters (pace, rhythm and variability) in older adults during normal walking and during dual-task conditions (walking while spelling five letter words backwards). They included twenty-four (24) community ambulators (13 men and 11 women; age: 67 to 87 years) in the study (community ambulators). The Gait Rite carpet was used for data collection. Participants were instructed to walk at their preferred speed. Data was collected from three trials and thirteen (13) strides during normal walking and (fourteen) 14 strides during dual-task walking. For test retest reliability the second set of data collection was performed within 30 minutes after completing the first set. Mean gait velocity, cadence and variation in stride velocity defined as coefficient of variation were determined. The numbers of strides were estimated using the Spearmen-brown prophecy formula. The results state that the velocity in normal walking can be reliably measured with the data collected from approximately four strides and that from nine strides during dual tasking to obtain an ICC of >0.9. To assess cadence nine (9) strides are sufficient during normal walking whereas 20 strides are required during dual tasking. For variability in stride velocity adequate test retest reliability required 60 steps for walking alone and over 300 steps were required for dual-task conditions. This study does not examine important spatio temporal gait variables such as stance time, double support time or step width. These results indicate that use of over ground walking to assess gait is insufficient as the number of steps are less. Hence, the use of a treadmill to record spatial and temporal gait variables from hundreds of consecutive steps is necessary.

### *2.6 Dual Task Effects on Walking*

Numerous studies have been published in last ten years that examine the effect of secondary concurrent tasks on gait parameters. Yahya et al., (2011) quantitatively assessed the effect of 1) reaction time task; 2) discriminating and decision making task; 3) mental tracking task; 4) working memory task and 5) verbal fluency task on gait speed, cadence and stride time variability. The following findings were presented: 1) gait speed was decreased significantly during dual-task conditions; 2) cadence and stride length were decreased during dual-task conditions; 3) the variation in the stride time was increased during dual-task conditions; 4) the mean difference of the scores for verbal fluency task and working memory task were greatest, 5) the mean difference of the scores for decision making tasks, reaction time and mental tracking tasks were lowest.

In a study conducted by Van Iersel et al., (2007), they examined the effect of dual-tasks on gait velocity, stride length, stride time variation, ML and AP angular velocities of the trunk. They included 59 participants (mean age 73.5 years) who are physically and mentally fit. Participants performed the following tasks: 1) walking at a self-selected speed; 2) walking while performing concurrent tasks. The concurrent tasks involved subtracting 7 from 100s and 13 from 100s, and citing words starting with letter

K and L. They used a Gait Rite carpet to record gait velocity and 2 angular velocity transducers (Sway star) attached on the trunk and lumbar region with the use of belt to record angular velocity in the medio-lateral and antero-posterior direction. They observed a significant increase in amount of body sway during dual-task conditions. A significantly decreased gait velocity was observed during dual-task conditions. Stride length and stride time variability significantly increased during dual-task conditions. The concurrent task performances such as calculations and citing words were not affected during the dual-task conditions.

A study performed by Plummer-D'Aamato et al., (2011) examined the effects of age and dual-task conditions on gait speed and stride time variability. They included 21 healthy older adults (mean age 74.4 years) and 24 healthy young adults (mean age 22 years) in the study. Cognitive processing was assessed using MMSE scores and participants having scores more than or equal to 23 were selected. Participants were asked to perform following two cognitive tasks; 1) spontaneous speech (in this participants were asked to respond by narrating the answer to a stimulus question) and 2) an auditory Stroop test ( in this participants heard one high pitch and one low pitch word and they had to respond the pitch of the word and not the word itself). Then the participants walked on an oval track of 16.8 m length and 0.6 m wide for one minute at their self-preferred speed and again while performing the concurrent tasks. Gait parameters of average gait speed, CV of stride time were determined using 55 strides recorded from foot switches (B&L Engineering, Santa Ana, CA). The concurrent task responses were recorded using a wireless head set and the time taken to respond was used as the outcome measure of cognitive performance. The responses made whether correct or incorrect were not considered in the analysis. They observed that, the preferred gait speed was significantly slower in the older adult group compared to the young adult group. They also observed that the decrease in gait speed during dual tasking was significantly greater for the older adult group as compared to the young adult group. This was consistent with the findings of Steffen et al., (2002). Stride time variability was increased in the older adult group as compared to the young adult group during the dual-task conditions which is consistent with others (Hollman et al., 2007). In addition response times of cognitive tasks during the dual tasking were significantly greater for older adults as compared to young adults.

Theill et al., (2011) assessed effects of single and dual-task walking on gait speed in 711 participants (mean age 77.2± 6.2 years). The concurrent tasks included counting backwards from 50 dividing it by 2 and enumerating animal's names. The participants were characterized into two groups; 1) cognitively healthy and 2) cognitively impaired based on MMSE scores < 16 (Folstein et al., 1975). Mean gait velocity was calculated using approximately 4 to 5 steps on the Gait Rite carpet and the number of correct calculations and correct responses for enumerating animal names were recorded. They observed that the self-selected speed of cognitively impaired participant group was significantly lower than the cognitively healthy participant group. This finding was consistent with the findings of Beauchet et al., (2005); Dubost et al., (2006); Hausdroff et al., (2005). They also observed a significant decrease in gait velocity for cognitively impaired participants during dual tasking as compared to cognitively healthy participants. This was consistent with the findings of Beauchet et al., (2005); Monterro Odesso et al., (2009). Performances of arithmetic task and animal enumeration tasks during walking were significantly lower in cognitively impaired participants than in the cognitively healthy participants.

Muir et al., (2011) examined effects of performing concurrent tasks such as Memorizing animal names; Counting backwards from 100; and Subtracting 7s consecutively starting from 100; on gait speed, stride time variability. They included 29 older adults with Mild Cognitive Impairment (MCI) (mean age 73 years), 23 patients with Alzeimer's Disease (AD) (mean age 77.5 years) and 22 cognitively normal participants (mean age 71 years) who did not have a previous history of falls. MMSE and Montreal Cognitive assessment (MoCA) scores were used to assess the levels of cognitive ability of the participants. All the participants walked only once during each task on the Gait Rite carpet, to record gait parameters from approximately 4-5 steps. The average gait velocity, stride time and coefficient of variation of stride time were determined. The observed results were: the gait velocity during dual tasking was significantly decreased in MCI and AD groups as compared to the control group. Also, during dual-task conditions stride time variability was significantly increased in MCI and AD group as compared to the control group. These findings were consistent with the findings of Peterson et al., (2005); Maquet et al., (2010). The control group performed significantly better in concurrent tasks than the MCI and AD groups.

Lamoth et al., (2011) examined thirteen (13) participants with dementia (mean age 82.6 years) and thirteen (13) without dementia (mean age 79.4 years) to study the effect of dual-task conditions on stride time and gait velocity under normal walking conditions and walking while performing letter fluency tasks (naming as many words as they could, starting with a pre-defined letter R or G). Participants were asked to walk for three (3) minutes in a 40 m long corridor that was well lit at self-selected speed (about 160 m total). As the participants performed the walking trials, trunk accelerations in antero posterior (AP), medio-lateral (ML) and vertical directions were measured with a tri-axial accelerometer fixed with an elastic band at the third lumbar level (L3). From the AP acceleration signal, time indices of left and right foot contacts were determined. Stride times were calculated from the foot contacts, by subtracting subsequent foot contact times of the same foot. One hundred fifty (150) successive strides were included in total for the analyses. The magnitudes of both AP and ML trunk accelerations time series data were calculated as RMS and peak accelerations within strides. They observed significant decrease in gait speed during dual-task conditions in participants with dementia as compared to the participants without dementia. Also, the stride time variability was increased during the dual-task condition in participants with dementia as compared to participants without dementia. The cognitive task performance of enumerating words during walking showed no significant difference between the two groups which is controversial to the study done by Muir et al., (2011).

### *2.7 Effects of speed on Gait Parameters*

There are numerous studies that demonstrate the influence of performing concurrent cognitive tasks on gait variables during walking. However the effects of change in gait speed on the other spatio temporal gait parameters is not studied explicitly. A study performed by Jordan et al., (2006), examined the effects of walking speed on the gait variables of stride time and stride length and vertical ground reaction force profiles. Participants were instructed to walk on a treadmill instrumented with two Kistler force plates at their preferred walking speed (PWS) and again at 80%, 90%, 100%, 110% and

120% of the selected speed. Eleven (11) female participants (mean age 24.9 ± 2.4 years) were included in the study. Six hundred and fifty strides were obtained from each walking speed. They observed a significant speed effect on stride time and stride length. The coefficient of variation of step length decreased significantly between 80% and the faster speeds. Also, the peak vertical ground reaction forces significantly increased with increasing treadmill speed. These results indicate that the change in gait speed affects other spatial and temporal gait variables and in order to assess the pure effects of cognitive task performance on spatial and temporal gait variability gait speed should be kept constant which is only possible by using a treadmill.

A study performed by Szturm et al., (2013), examined the effects of speed on temporal gait variables. Twenty healthy young adults (mean age 26.3± 3.2 years) were included in the study. Participants were asked to walk on treadmill at two different speeds (0.7 and 1 m/s) and foot pressure (COP) was recorded using insole sensors (FSA insole: Vista Medical Ltd). They used time indices of pressure onset and offset from right foot and computed the temporal gait parameters of stance time, swing time and double support time. Forty five steps per leg were used to compute the variables and the averages and COV of those variables which were used for analysis. They observed that an increase in walking speed significantly decreased the variation in the temporal gait variables.

A study performed by Stoquart et al., (2008), also examined the effect of speed on kinematics (stance phase duration and step frequency). They included 12 healthy young adults (mean age 23±2 years) in the study. Participants were asked to walk on a treadmill at six predefined speeds (1 to 6 km/hr). They embedded the treadmill with four customized three-dimensional strain-gauge force transducers that recorded the ground reaction forces and computed the step frequency and stance phase durations. They observed a significant increase in the step frequency and significant decrease in stance phase duration as the speed increased.

A study performed by Betker et al., (2006), examined the effects of over ground walking and treadmill walking speed on spatial and temporal gait parameters. A Gait Rite carpet was used for over ground walking. Participants were asked to walk on the carpet and the speed was matched accordingly for treadmill walking. They observed a significant decrease (100 ms) in stance time during treadmill walking as compared to over ground walking. Swing time was significantly increased (300 milli seconds) during treadmill walking. The study also observed that participants had a longer swing phase than stance phase during treadmill walking.

## Statement of Problem

Walking is a complex motor skill and is closely linked to cognitive functioning Dubost et al, (2005); Rosano et al., (2007); Ambrose et al., (2006); Buchman et al., (2011). The most common and consistent finding of dual-task studies comparing walking alone to walking plus performing concurrent tasks has been the reduction in gait speed. Effects of gait speed on other important spatial temporal gait variables such as single support time, step time, swing time, step width, step length are usually not considered in the analysis. Many studies such as Szturm et al., (2013), Kizony et al., (2010); Betker et al., (2008); Stoquart et al., (2008); Dingwell et al., (2006); Jordon et al., (2006) show that as the gait speed changes, variation of the other spatial and temporal gait parameters either increases or decreases. Thus the pure effects of concurrent cognitive tasks cannot be measured and the data may be misinterpreted.

Dual-Task studies have quantified gait variables using data collected from a few steps, (4 to 5 steps) using the Gait Rite carpet. However the reliability in this data remains questionable. Studies have reported that more than 100 steps are required to observe a good reliability score for the spatial temporal gait parameters (Hollman et al., 2010). Also, as the number of steps increases, the COV for the gait variables increases (Hollman et al., 2010). In most over ground dual-task walking studies the walking task and the concurrent cognitive task is only performed for a few meters or for few seconds. These limitations result in recording data from only a few consecutive walking steps.

The concurrent cognitive tasks used in most of the studies are not graded explicitly. They are usually graded by the number of responses made or reaction time, but they do not evaluate the accuracy of the response given. This method of analysis can lead to misinterpretation of the data thus affecting the results. Studies performed by Betker et al., 2006; Herman T et al., (2010); Hobert et al., (2011); Alyahya et al., (2011); Szturm et al., (2013) have shown that not only the objective measures (i.e. success rate of the task) but also the process measures (i.e. how the task gets performed) should be examined. The use of visual spatial cognitive processing tasks allows assessment of large spectrum executive cognitive functions (such as decision making, processing speed, set thinking) depending on the different levels of complexity of the task.

In order to explore further the interaction between cognitive and walking demands on stability we have developed a computer game based treadmill rehabilitation platform. By using this tool we are able to evaluate balance performance, locomotor skills and the visual spatial cognitive game task performance all together. As studies have shown that gait speed being an important factor affecting gait parameters, we can hold the treadmill speed constant within and between participants. A pressure mat was embedded in thick Teflon and was mounted beneath the treadmill belt. This allowed us to record the foot contacts (COP pressures) and based on those we extracted the various spatial and temporal gait parameters from hundreds of steps while the participants performed single as well as dual-task walking. Visual spatial cognitive game tasks used in the study allowed us to record the head movements during the tracking tasks as well as cognitive ability during cognitive game tasks.

## Study Purpose and Objectives

Development of community resources and programs that allow inexpensive long-term support for older adults with cognitive and mobility decline has become one of the most important necessities, today. The primary purpose of the present study was to validate the treadmill rehabilitation platform (TRP) that assessed standing balance performance; spatial and temporal gait parameters; stability measures and visual spatial cognitive task performances under single and dual-task conditions.

### Objective 1

To examine the test retest reliability of the new TRP tool measures that assessed standing balance, gait, stability, tracking and cognitive task performances.

### Objective 2

To examine the effects that increasing visual and cognitive load had on standing balance, gait and stability during walking. We also examined how increased physical load affected visual tracking and cognitive game task performances.

### Hypotheses

1. Moderate to high test retest reliability scores will be obtained for the new TRP tool measures that assessed standing balance, gait, stability, tracking and cognitive task performances
2. Increased visual task demand will decrease standing balance performance by increasing COP excursions
3. During walking, increased visual task demand will increase the spatial and temporal gait variability and decrease walking stability.
4. Increased physical load will decrease the visual tracking and cognitive game task performances
5. When there is increase in both visual and physical load during standing there will be a decrease in stability indicated by a increase in COP excursion (RMS COP excursions in AP and ML directions)

# Chapter 3: Methods

## *3.1 Sample Size Calculation*

For the test retest reliability, sample size was calculated based on our previous study, Desai et al., (2010). It was determined that 28 participants would be required by using a one sided 95% Confidence Interval (CI) and each outcome will be sampled eight times in a testing protocol.

## *3.2 Ethics Approval*

The study protocol was approved by the Human Research Ethics Board, Bannatyne Campus; University of Manitoba (H2011:284).

## *3.3 Study Participants*

### Recruitment

Participants were recruited from the Reh Fit center, Winnipeg, MB, where individuals come for leisure, recreational activities or exercises.

### Inclusion Criteria

Community dwelling healthy individuals aged between 55 to 75 years (Mean age 61.4±4.4 years) and who could perform daily activities without any assistance were included.

### Exclusion Criteria

People with cardio-vascular risks determined by the testing conducted at the Reh Fit center, dementia, stroke, Multiple Sclerosis, ALS, Brain tumor or Parkinson’s disease were excluded. Neuro psychological deficits screened using the MoCA (Montreal

Cognitive Assessment Scale) were excluded. All the tests were initially performed by the clinical staff of Reh Fit center.

### *3.4 Study Setting*

The equipment was situated in the Cardiac Fitness Laboratory of the Reh Fit Center, Winnipeg, Manitoba.

### *3.5 Instruments and Data recording*

#### Treadmill with FSA pressure mapping mat

Figure 1 below represents the treadmill instrumented with a force sensory array mat used to record spatial and temporal gait parameters. A treadmill (SportsArt Fitness Ltd, Taiwan) with hand rails and an overhead harness to provide safety while performing the tasks was used. A Force Sensor Array (FSA) mat (Vista Medicals Ltd, Winnipeg, Canada) embedded in thick Teflon was placed underneath the treadmill belt for recording the COP excursions while walking on treadmill. The FSA Pressure Array mat has 512 sensors (16 by 32) and each sensor covers area of 2.8 $cm^2$. It is similar to the Gait Rite carpet, but as it is embedded underneath the treadmill belt recording of COP excursions during hundreds of steps was possible at a fixed speed. Foot contacts (time indices) and COP excursions were used to extract spatial and temporal gait parameters.

**Figure 1:** Treadmill instrumented with a force sensory array mat

### Standing FSA Pressure Sensor Array mat

Figure 2 below represents standing FSA mat used to record COP excursions during standing. It was used to record the COP excursions during standing on a Fixed and Compliant Sponge surface. It has 256 sensors (16 by 16) and each sensor covers area of 2.8 $cm^2$. COP excursions during standing alone and while performing tracking and episodic game tasks were recorded under fixed and sponge surface conditions and used for analysis.

**Figure 2**: Standing FSA mat used to record COP excursions.

### Motion Monitor

Figure 3 below represents a photo of motion monitors used in the present study to record trunk angular velocities while performing single and dual-tasks during standing and walking. The inertial motion monitors (Nex-Gen Ltd, Quebec, Canada) are cube like sensors, which are wireless and have a range more than 30 m for recording data. Each monitor has an accelerometer, gyroscope and magnetometer which collect data in all three directions (AP/ML/VR). They were secured and attached on to the participants with the help of elastic belts: one on the sternum, one on pelvis and one on the lateral aspect of the ankle. Trunk angular velocity during standing on fixed and sponge surface was recorded. During walking, the artifact from ankle vertical acceleration was used to parse individual step data of trunk angular velocity ML. The Average of the variance calculated from each step was used for analysis.

**Figure 3:** Motion monitor used for parsing the trunk angular velocity data while performing single and dual-tasks during walking.

### Air Mouse

Figure 4 below represents the Air mouse (Gyration, California) mounted on a helmet which was used for the interaction with the computer screen to perform the tracking and cognitive game tasks. The inexpensive commercial Gyration Air Mouse which has been thoroughly tested (Shih et al., 2010; 2011) was attached on to a helmet. Participants wore the helmet which allowed them to interact with the on-screen cursor through head rotation while keeping the hands free. This air mouse uses the inertial sensors to derive angular displacement signals and can be used in a way similar to a normal computer mouse. The participants head rotation controlled the user cursor movements on the screen.

**Figure 4**: Gyration Air mouse mounted on a helmet with Velcro

### Interactive Computer game Application

A game application was developed which recorded the co-ordinates of the participant’s head movements and those co-ordinates were used for the analysis. The game application had two assessment modules which recorded the ability to track the target cursor on the screen (visual tracking module) and catch the targets that are falling vertically down from the top of the screen (cognitive game module).

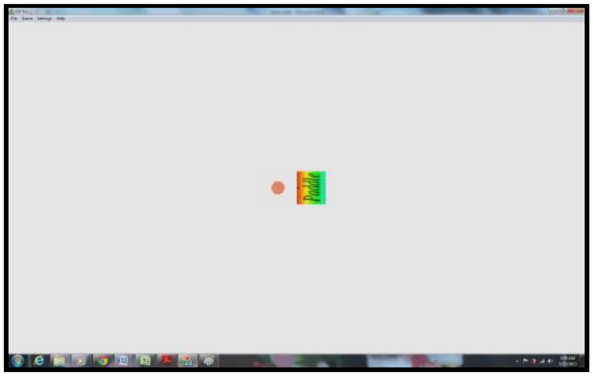
### Visual Tracking Module

A tracking task was developed which included horizontal sinusoidal movement of an on-screen cursor (a bright-colored circle). The frequency and the amplitude of the sinusoidal movements were pre-defined (frequency: 0.7 and amplitude: 0.40). Following are the two tracking tasks included in this module:

### Closed Loop Smooth Pursuit Tracking Task with respect to head rotation

Figure 5 below represents a snap shot of the closed loop tracking condition. The target cursor as well as the paddle which is slaved to the participants head rotation is visible in the picture. In this, the participants were asked to rotate their head in concert with the moving target cursor and overlap the paddle on the target. There were two cursors of different colors appearing on the screen. One was the target cursor which was moving left to right. The motion of the second cursor was slaved to the head rotation via the head tracking mouse (Air mouse). The goal of this task was to overlap the two cursors during the motion of the target cursor from left to right. This task required foveation to determine the amount of overlap (error) between the target cursor and the head cursor. Participants were asked to perform this task for 45 seconds in standing as well as while walking.

**Figure 5:** Snap shot of the closed loop tracking task



### Open Loop Smooth Pursuit Tracking Task with respect to head rotation

In this the participants were asked to rotate their head in concert with the motion of the target cursor. This required a peripheral and central occulo-motor following mechanism and not continuous foveation. Participants were asked to perform this task for 45 seconds in standing as well as while walking.

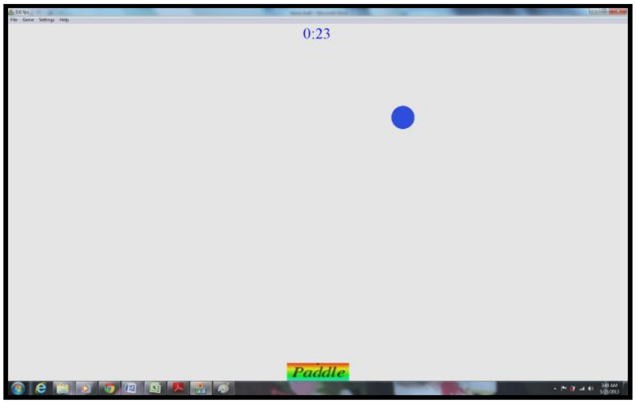
### Cognitive Game Module

For the episodic random game condition, a custom-built computer game that evaluates the targeted executive functions was built. (For example: visual spatial processing, cognitive interference and processing speed). The episodic random game design is based on a classic paddle-based game. In this the participants had to move the game sprite (that is the paddle) to catch targets that are moving, falling down on the screen one at a time at a constant speed. The movement of the game sprite was slaved to the head rotation through the air mouse. The target object appeared every two seconds at random locations on the monitor from the center to the edge. The number of targets hit, the time taken to reach the target location from the paddle initial location and the time from the appearance of the target to the start of the paddle movement was recorded automatically and used for the analysis. The computer game based cognitive tasks included two different complexity levels; Simple and Moderate.

### Simple cognitive game task:

Figure 6 below represents a snap shot of the simple cognitive game task in which the target is falling down on the screen and the paddle slaved to the participants head rotation is seen. In this the participants were presented with a single target that appeared on the screen on the top and moved vertically downwards. The participants had to move the game sprite (paddle) by rotating their head to catch the target object (bright-colored circle). This was performed for 60 seconds while standing on fixed and sponge surface and for 120 seconds while walking on the treadmill.

**Figure 6:** Snap shot of the simple cognitive game task



**Moderate cognitive game task:**

Figure 7 below represents a snap shot of the moderate cognitive game task in which the target is falling down along with a distracter (sphere shaped), on the screen and the paddle slaved to the participants head rotation is seen. This was similar to the simple game task but the difference was in that the target that appears vertically top to bottom. In this there was one sphere shaped object added that appeared randomly and which was a distracter. If an attempt was made to hit that object (distracter) then the game sprite (paddle) would be destroyed. This task was performed for 60 seconds while standing on fixed and sponge surface and for 90 seconds while walking on the treadmill.

**Figure 7:** Snap shot of the moderate cognitive game task

### *3.6 Study Protocol*

**Test Day 1**: Brief explanations and demonstrations of the tasks included in the TRP test protocol were given to all the participants on their first visit and they were asked to sign the consent form before they started with the protocol. After completion of the consent, they were allowed to play the visual tracking and the cognitive game tasks in standing to familiarize themselves with the tasks. Then three wireless motion monitors were attached on to them using the elastic belts: one on the sternum, one on the pelvis (L5 level) and one on the lateral aspect of the ankle. The following functional tests were performed by the participants before they were engaged in visual spatial cognitive tasks from the TRP protocol.

1) Tandem gait for 10 meters: Participants were asked to walk heel-toe-touch on a 10 meter carpet and they were graded based on visual observation. Performance was graded using following five levels: 5= excellent; 4= good; 3= fair; 2= poor and 1= cannot do.

2) One leg standing for a maximum of 15 seconds: Participants were asked to stand on one leg on the standing FSA mat on the treadmill (hand rails provided safety if the participants experienced any loss of balance). COP excursions during one leg stand were recorded. Participants were asked to start with the right leg and then left leg.

3) Eyes open and Closed conditions: Participants were asked to stand on a fixed and sponge surface with eyes open for 45 seconds and then eyes closed for 45 seconds with a rest period of one minute.  This was performed on the treadmill as it has safety hand rails which provided easy and quick support if the participants experienced loss of balance. The change in support surface and the change in visual stimuli can be correlated to the

tasks performed in the MCTSIB conditions as it consists of four conditions: Standing on fixed and compliant surface while eyes open and eyes closed.

Participants were then instructed to perform each of the visual tracking and cognitive game tasks from the TRP protocol while they were standing on a fixed surface; sponge surface with a wooden board on it; and while walking on treadmill at a speed of 0.9 m/s. Participants were also asked to walk alone on the treadmill at a speed of 0.9 m/s for 4 minutes before they were engaged in the tracking and game tasks. This allowed us to record the COP excursions and foot placements during normal walking and to compute their normal spatial and temporal gait parameters. The order at which the visual tracking and the cognitive game tasks during standing and walking were performed was randomized so that they would remain unpredictable.

Then the participants were provided with a questionnaire (CHAMPS) that assessed the intensity and the frequency of their participation in various activities such as walking, gardening, housework, sports activities, and volunteering. The Community Healthy Activities Model Program for Seniors (CHAMPS) is a physical activity questionnaire which covered various aspects of the concept of participation. The CHAMPS was observed to have a moderate to high test retest reliability (ICC: 0.7 to 0.8) when applied to assess Australian older adults, Giles et al., (2009). The CHAMPS may be appropriate to measure the effectiveness of programs, which are built to increase the physical activity level in older adults (Stewart et al., 2001). Participants were asked to complete the questionnaire at home as per their convenience and return at the time of the second session. To summarize, the day 1 session took around 60 minutes and involved; Background information, screening tests and consent; and TRP protocol testing.

**Test Day 2**: The second session was about 45 minutes and it included:

1) Retests of the TRP protocol tasks performed on Test Day 1 while standing on sponge surface and during walking.
2) Six-minute walk test: Participants were asked to walk on the track of Reh Fit Center for six minutes and the distance was recorded. A review done by Du H et al., (2010) observed a strong association of six minute walk distance with the functional capacity and the use of six minute walk test as a prognostic tool.

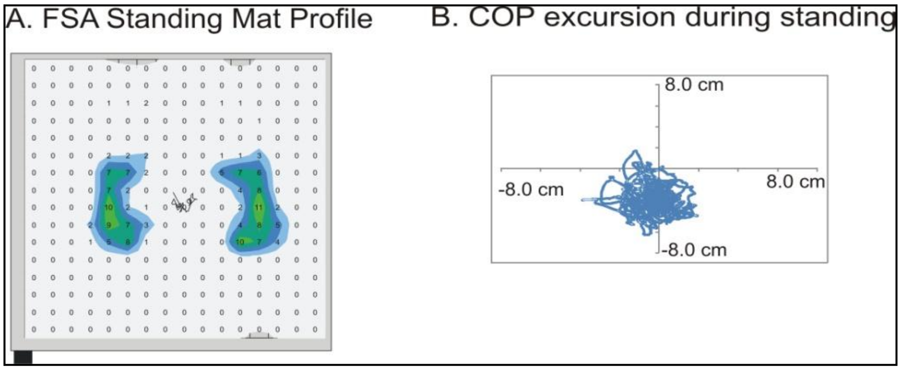
### *3.7 Data Analysis*

Custom built Mat lab scripts (Math Works, Natick, MA) were used for extracting all the dependent variables from the data recorded:

### Core Balance

1) Standing Balance: Antero-posterior (AP) and Medio-lateral (ML) COP excursions during various standing tasks were recorded. Root mean Square (RMS) of the COP excursion in AP and ML directions was derived and used as stability measure, Desai et al., (2010). (Figure 8 Panel A and B)

**Figure 8:** Snapshot of the left and right foot COP excursions while standing on FSA mat. **Panel A** represents a snapshot of the left and right foot while standing on fixed surface FSA mat. **Panel B** represents the XY plot of COP excursions during stand-alone condition.



2) Spatial and Temporal gait parameters: The vertical COP in AP and ML directions were recorded by using the treadmill pressure mat and were used after summing the contact forces (foot pressure) during normal and dual-task walking. Figure 9 panels A, B, C represents the instrumented treadmill; snapshot of the treadmill pressure mat recordings from a normal walk, XY plot of COP displacements and the AP and ML displacements of the COP. The AP and ML displacements shown in Figure 9 panel D were analyzed using custom built Mat lab script to compute the following spatial and temporal gait parameters:

Temporal Variables

1) Single Support Time: the amount of time the foot is on ground that is, when there is pressure over the matt.
2) Swing time: the amount of time the foot is not in contact with the ground, so there is no pressure available on the mat.

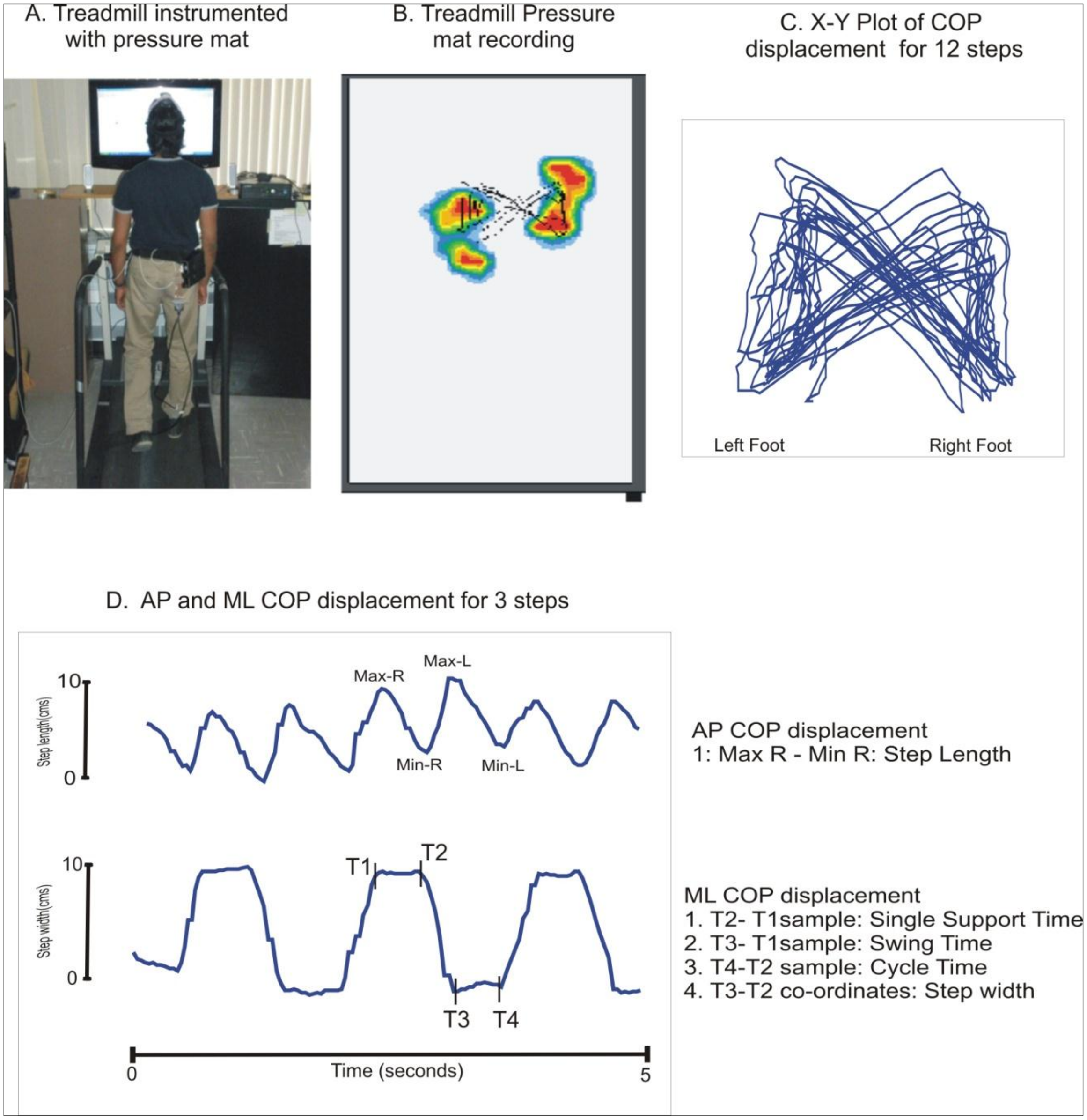
3) Cycle time: the time taken by one foot from its initial contact of the cycle to the next initial contact of the next gait cycle.

Spatial Variables

1) Step length: The distance between the points of contact of one foot to the same point of contact with the other foot.
2) Step width: The side to side distance between the feet.

The above spatial and temporal gait variables have been identified based on their associations with adverse health outcomes such as falls and when they are subjected to factor analysis they can be divided into three major independent indicators (Pace, Rhythm and Variability). They included velocity, stride length and double limb support time in the “Pace” factor. The “Rhythm” factor consisted mainly of cadence, swing time and stance time. Variability was the third factor which affected 16% of the variance in gait performance, and that included stride length variability and stride time variability for consideration. Studies have also shown that these variables have a strong association with the increase in the adverse health events i.e. falls (Verghese et al., 2008; 2009; Hollman et al., 2011; Hausdorff et al., 2005; Szturm et al., 2011). The Average and coefficient of variation (COV) of the above gait variables were computed and used for the analysis of normal as well as dual-task walking. Average values of the spatial and temporal gait variables during normal walk and dual-task walking were used to obtain the reliability scores as studies have observed low reliability scores for coefficient of variance due to less difference in the averages of the two test sessions, Beauchet et al., (2011).

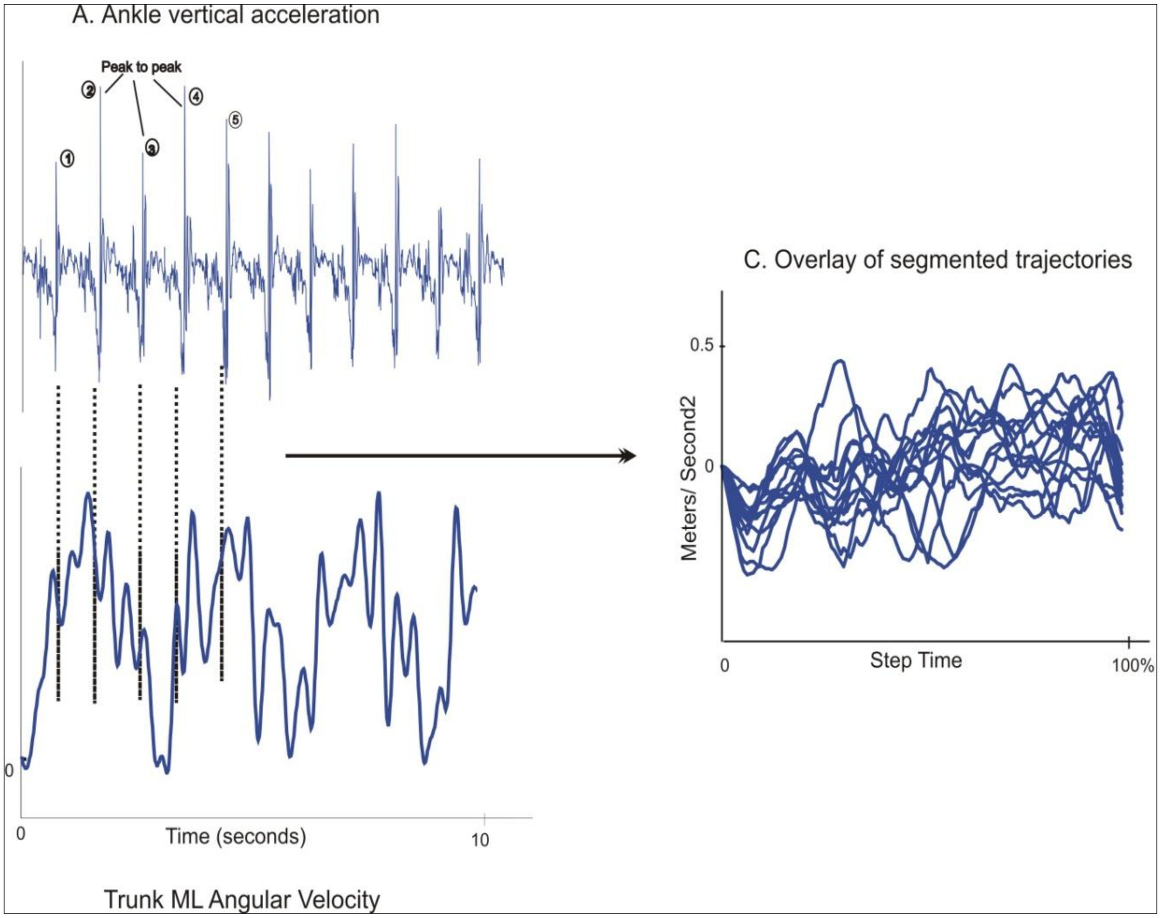
**Figure 9: Panel A**: Photo of the Experimental set-up. Participant is shown while walking on treadmill and performing head rotations (with the help the air mouse) to interact with computer tracking and cognitive tasks.  **Panel B:** Snapshot of left and right foot-ground vertical force profiles recorded during normal walking. **Panel C:** X-Y plots of COP displacement for almost 10 to 12 steps. **Panel D:** AP and ML COP time series data for 3 to 4 steps and quantification of the spatial and temporal gait variables.



### Motion Monitor data

Figure 10 represents the use of large amplitude spikes obtained from the vertical acceleration of the ankle motion monitor to parse the angular velocity data during individual steps. The trunk angular velocity data provided by the motion monitors during different physical and visual task conditions was used for the analysis. ML trunk angular velocities recorded during standing conditions were used to assess the stability during standing on the fixed and sponge surface. Root Mean Square (RMS) was computed for analysis purposes. The angular trunk velocities during walking conditions were parsed to obtain individual step variations in trunk movements with the help of large amplitude spikes from the trigger channel (i.e. vertical acceleration of ankle). Studies performed by Tien et al., (2010); Doi et al., (2011); Picerno et al., (2011) used similar methods to analyze the individual step variations in trunk and pelvis linear accelerations and angular velocities. Average of the variance for trunk angular velocity cut data during individual step times was used to determine the stability during walking Doi et al., (2011). The motion of the trunk is a main contributor to overall stability during walking (normal as well as dual-task walking), (Dingwell et al., 2008; Lambert et al., 2010).

**Figure 10:** Parsing of the trunk angular velocity data using vertical acceleration of the ankle during individual steps.

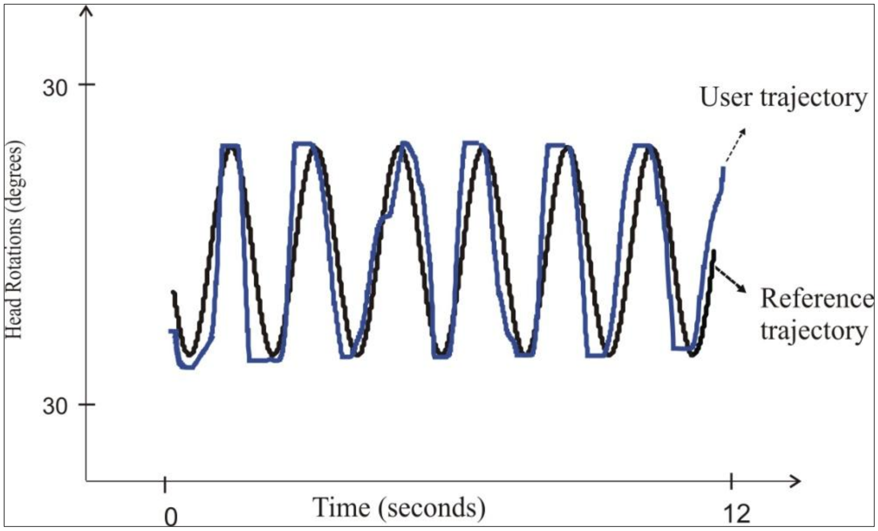


## Visual Tracking Task Performance Measures

Figure 11 represents the method of analyzing the quality of tracking (head rotation) by using the reference and the user signals recorded during the performance. A nonlinear least square algorithm was used to obtain the sine wave function of the user signal trajectory fitted against the reference signal to extract the variable of Coefficient of Determination (COD). During the tracking task, the co-ordinates and time intervals of each event of the reference signal (computer cursor movement) and the user signal (horizontal head rotations) were used to compute the primary variable of Coefficient of

Determination (COD). This represents the quality of tracking i.e. the sinusoidal movements of the user signal with regards to the reference signal. The use of the sinusoidal movement of the reference target to facilitate head rotation can provide a feedback about the participants head rotations (Pinsault et al., 2006; 2008; Kristjansson et al., 2004).

**Figure 11:** Analysis of tracking task performances



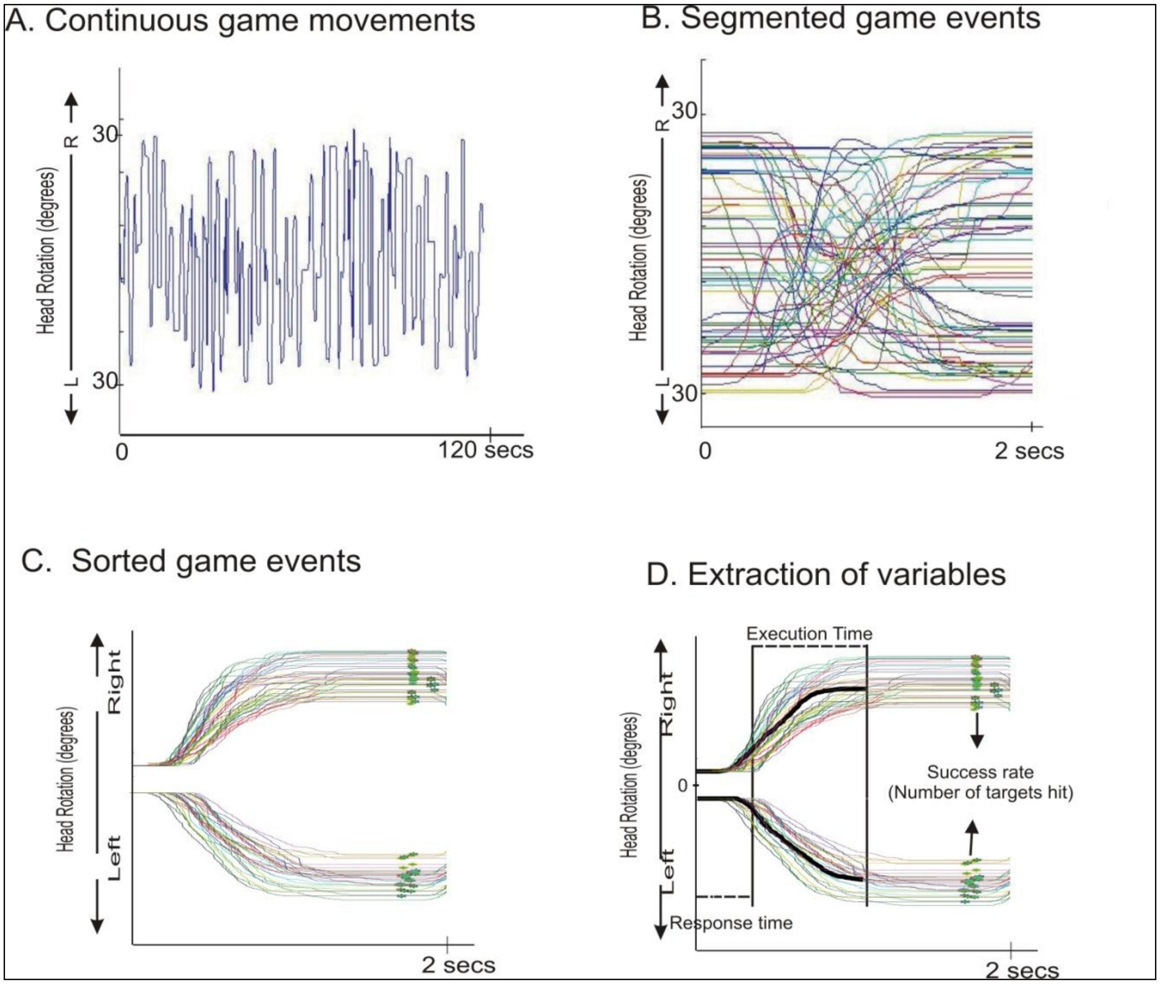
## Cognitive Game Task Performance Measures

Figure 12 represents the analysis method of cognitive game task performances. Panel A represents the trajectory of game paddle movements (head rotation) during the cognitive game task performed for 120 seconds duration (x-axis). Each game event is 2 seconds in length, resulting in recording a total of 60 game events. Panel B represents the overlay of individual game events, segmented based on time of the target appearance and hitting the paddle from player movement shown in panel A. Time zero is onset of target appearance on the top of the screen (event onset), and the end of the event is time when the target is either hit by the paddle or as it disappears. Panel C represents the segmented game events shown in panel B that are sorted and grouped in functional bins, which in this case represent medium amplitude player movements in the left direction (upward trajectories), and right direction (downward trajectories). Panel D illustrates analysis methods to quantify response time and movement time from the grouping of leftward, medium amplitude game events of one trial. The following variables were extracted from the data recorded:

1) Averaged motor response time: It is the time from the appearance of the target to the start of the paddle movement.
2) Average movement execution time: the time taken to reach the target location from the paddle initial location.
3) Success Rate: The number of targets hit are recorded and used for analysis.

The method of segmenting and analyzing of cognitive game events (contextual outcomes) is crucial as it provides averaged performance measures, over repeated trials, Song et al., (2009).

**Figure 12: Panel A:** Trajectory of game paddle movements (head rotation); **Panel B:** Overlay of individual game events, segmented based on time of the target appearance; **Panel C:** Segmented game events; **Panel D:** Extraction of the variables



## CHAMPS

The Community Healthy Activities Model Program for Seniors (CHAMPS), Stewart et al., (2001) which is a physical activity questionnaire that covered various aspects of the concept of participation was used to assess the intensity and frequency of participation in various activities such as walking, gardening, housework, sports activities, and volunteering.

# Chapter 4: Statistical Analysis

IBM SPSS software for Windows, Version 20.0 (SPSS Inc. Chicago, IL, USA) was used to perform all the statistical analysis in the present study.

To evaluate the test retest reliability of the new TRP tool measures Relative reliability was assessed using the intra-class correlation coefficient (ICC $_{(2,1)}$) and the Absolute reliability was analyzed using Standard error of Measurement [SEM= SD*√ (1-ICC); where SD is the average standard deviation of the test measures and ICC is the reliability coefficient of the test measures], Adsaur et al., (2013); Weir et al., (2005). ICC scores were interpreted as high= > 0.70; moderate= 0.5 to 0.69 and Low= < 0.50 (Shrout and Fleiss., 1979). The variance between the two test sessions was also evaluated using t-test (Adsaur et al., (2013), Batterhama et al., (2003)). Alpha or the level of significance for the t tests was set to 0.05. SEM percentage was computed using the following formula: SEM/Pooled average*100. This would give an estimate of measurement error.

To examine the effects of the increase in physical loads on tracking and cognitive task performance, one way repeated measures ANOVA was used. Bonferroni correction pair wise comparison was done to show how the averages differed from each other. To examine the interaction effect of increase in physical load and visual task load on core standing balance measure of RMS COP excursion in ML and AP direction, two-way ANOVA was used. Alpha or the significance level was set at 0.05. Descriptive statistics (mean and standard deviation) were also computed for the normally distributed variables.

I. One way ANOVA ($\alpha$=0.05) was used to test the following hypotheses:

1. Increased visual task demand will decrease standing balance performance by increasing COP excursions

Fixed/ Independent factors: Visual tasks of tracking and cognitive game.

Random/ Dependent factors: Core balance measures (RMS COP excursions in AP and ML direction).

2. During walking, increased visual task demand will increase the spatial and temporal gait variability and decrease walking stability.

   Fixed/ Independent factors: Visual tasks of tracking and cognitive game.

   Random/ Dependent factors: Average and the COV of the Spatial and Temporal gait parameters; Stability (average of the variance of the trunk angular velocity during walking).

3. Increased physical load will decrease the visual tracking and cognitive game task performances

   Fixed / Independent Factors: Physical conditions of Fixed Surface, Sponge Surface and Walking.

   Random/ Dependent Factors: Tracking task variable (COD) and Cognitive task measures (Success rate, Average Response time and Average Execution time).

II. Two ways ANOVA (α= 0.05) was used to test the effect of Factor A on Factor B and also the following hypothesis:

1. When there is increase in both visual and physical load during standing there will be decrease in stability due to increase in COP excursion (RMS COP excursions in AP and ML directions)

Fixed/ Independent factors: Standing on fixed and sponge surfaces, Visual tasks (tracking and cognitive game)

Random/ Dependent factors: RMS amplitude of COP excursions in AP and ML direction.

## Chapter 5: Results

Thirty participants (mean age 61.4±4.4 years) were included in the present study. The new TRP protocol was used to assess standing balance, gait, stability, tracking and cognitive task performances and the demographic and initial test results are presented in Table 1. Tandem gait was graded based on visual observations and it ranged from poor to fair (i.e. 2.75±0.48). The average distance travelled in six minutes was 562m. Distance covered by population aged 60 to 69 years= 572 m (Steffen et al., 2002). CHAMPS scores revealed low intensity and frequency measures of participation in physical activity. Time taken to complete the Trail making test A was 44.03 s and for test B it was 100.63s. The total numbers of errors were more during test B (12.13± 9.24) as compared to test A (9.41± 7.8). Thus when the complexity of the test was increased, both, time to complete the test and the number of errors increased.

**Table 1:** Demographic information; Group means and standard deviation for Tandem walk grades, Six minute walk test, Trail Making test times and CHAMPS scores

| Demographic Data | Mean± SD |
|---|---|
| Age (years) | 61.4± 4.4 years |
| Gender ratio<br>Males: Females | 26: 4 |
| Tandem Walk Grade | 2.75±0.48 (Poor to Fair) |
| Six Minute Walk Test | 562 (m) |
| Champs<br>Intensity<br>Frequency | 1.29±0.39<br>1.23±0.46 |
| Trail Making Test A<br>Trail Making Test B | Total Time= 44.03± 12.05 (s)<br>Number of errors= 9.4± 7.8<br>Total Time= 100.63± 91.48 (s)<br>Number of errors=12.13±9.24 |

## *5.1 Test Retest Reliability*

### 5.1.1 Standing Balance

Table 2a shows the ICC scores; SEM scores and t statistics for COP excursions in AP directions recorded during the following conditions: Eyes Open, Eyes Closed, Open loop and Closed Loop tracking, Simple and Moderate cognitive game tasks. Table 2b shows the ICC scores; SEM scores and t statistics for COP excursions in ML directions recorded during the following conditions: Eyes Open, Eyes Closed, Open loop and Closed Loop tracking; Simple and Moderate cognitive game tasks. ICC scores for both AP and ML COP excursions were high when the task load was easier but as the task load increased reliability scores decreased to moderate (i.e. during standing alone it had high ICC score whereas during tracking and cognitive game tasks it was observed to be moderate). The overall SEM scores were observed to increase as the task load was increased.

The ICC score for the RMS amplitude of COP excursions in both AP and ML directions during Eyes open and closed condition was moderate (ICC= 0.6). While performing the Open loop tracking task, the RMS amplitude in both AP and ML directions had moderate ICC scores (ICC =0.6). While performing the closed loop tracking task, the RMS amplitude in the AP direction had a moderate ICC score, and in the ML direction it had a high ICC score (ICC= 0.7). When a simple cognitive game task was performed, the RMS amplitude in the AP direction showed high ICC score, whereas, in the ML direction it had a moderate ICC score. And when a moderate game task was performed, RMS amplitudes in both AP and ML directions showed moderate ICC scores.

Standard Error of Measurement (SEM) for the above conditions ranged from 0.2 to 0.4. It was observed that as the visual task load increased, SEM scores increased. The SEM during eyes open and closed condition was observed to be 7% and 8%, whereas during open loop and moderate game task conditions it was increased to 8% and 10% respectively.

**Table 2a:** Results of statistical analysis, ICC scores, SEM and t statistics for COP AP excursion.

| Variable (**RMS COP excursion AP**); (cm) | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
|---|---|---|---|---|---|
| Eyes open | 0.5* | 0.23 | 2.16(0.9) | 2.03(0.8) | NS |
| Eyes Closed | 0.6* | 0.4 | 5.08(2.03) | 5.33(2.2) | NS |
| Open Loop | 0.6* | 0.4 | 4.8(1.54) | 4.7(0.68) | NS |
| Closed Loop | 0.6* | 0.3 | 3.04(1.22) | 2.28(1.27) | NS |
| Simple Game Task (G1) | 0.7* | 0.2 | 3.55(1.39) | 4.5(1.52) | 0.01(2.5, 29) |
| Moderate Game Task (G2) | 0.6* | 0.4 | 4.06(1.77) | 4.8(2.03) | 0.02(2.3, 29) |

Significant correlation* ($p < 0.05$); NS=Not Significant

**Table 2b:** Results of statistical analysis, ICC scores, SEM and t statistics for COP ML excursion

| Variable (**RMS COP excursion ML**); (cm) | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
|---|---|---|---|---|---|
| Eyes open | 0.5* | 0.3 | 1.9(1.1) | 1.8(0.7) | NS |
| Eyes Closed | 0.6* | 0.4 | 3.8(2) | 3.3(1.1) | NS |
| Open Loop | 0.5 | 0.2 | 2.3(0.91) | 2.08(0.61) | NS |
| Closed Loop | 0.7* | 0.2 | 2.9(1.04) | 2.41(0.68) | NS |
| Simple Game Task (G1) | 0.5 | 0.2 | 2.51(0.89) | 1.77(0.43) | 0.0(5.47, 29) |
| Moderate Game Task (G2) | 0.5 | 0.2 | 2.54(1.09) | 1.98(0.53) | 0.0(3.9, 29) |

Significant correlation* ($p < 0.05$); NS= Not Significant

### 5.1.2 Spatial and Temporal Gait Variables

Table 3a, 3b, 3c represents test retest group means; standard deviations; ICC scores; SEM scores and t statistics for the spatial and temporal gait variables recorded during normal walking and walking while performing visual tasks (i.e. table 3a: normal walking; 3b: walking while performing tracking tasks; and 3c: walking while performing cognitive game tasks). ICC scores for spatial and temporal gait variables during normal walking and walking while performing the visual tasks ranged from moderate to high. As the visual task load was increased, ICC decreased and SEM increased. A t-test showed no significant difference between test retest group means of spatial and temporal gait variables during normal walking as well as walking while performing tracking and cognitive game tasks.

During normal walking, Single Support time (SST), Swing time, Cycle time and Step length had moderate reliability scores, whereas Step width had an excellent reliability score. When the open loop tracking task was performed while walking on treadmill, SST, cycle time and step length had a low reliability score, whereas averaged swing time and step width had a moderate reliability score. And when the closed loop tracking task was performed, all the spatial and temporal gait variables had moderate reliability scores. While performing both simple and moderate cognitive game tasks all the spatial and temporal gait variables had moderate reliability scores.

The SEM for the gait variables during normal walking ranged from 6% to 10%. During the open loop tracking task it ranged from 12% to 16% and during the closed loop task it ranged from 9% to 13%. During the simple cognitive game task it ranged from 9%

to 12% and while moderate cognitive game tasks it ranged from 10% to 13%. Thus when task load was increased SEM increased.

**Table 3a:** Results of statistical analysis, ICC scores, SEM and t statistics for the spatial and temporal gait parameters during normal walking

| Variable **Spatial And Temporal Gait variables** while **Normal Walking** | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
|---|---|---|---|---|---|
| Single Support time (ms) | 0.6* | 1.2 | 354.5(59.39) | 360.6(55.7) | NS |
| Swing time(ms) | 0.5 | 1.9 | 421.8(75.7) | 460.9(88.2) | NS |
| Cycle time (ms) | 0.6* | 1.5 | 792.12(91.6) | 811.21(116.0) | NS |
| Step length(cm) | 0.5* | 1.3 | 10.13(1.71) | 10.36(1.89) | NS |
| Step width (cm) | 0.7* | 1.1 | 11.75(2.01) | 11.11(2.06) | NS |

Significant correlation* ($p < 0.05$); NS= Not Significant

**Table 3b:** Results of statistical analysis, ICC scores, SEM and t statistics for the spatial and temporal gait parameters during walking while performing the two tracking tasks

| **Spatial And Temporal Gait variables** while performing **Open loop tacking task** | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
|---|---|---|---|---|---|
| Single Support time (ms) | 0.4* | 1.7 | 417.5(60.6) | 426.9(66.6) | NS |
| Swing time (ms) | 0.5 | 1.9 | 340.0(73.3) | 395.1(90.6) | 0.003(-3.2,29) |
| Cycle time (ms) | 0.2 | 2.1 | 650.9(84.5) | 730.3(56.9) | 0.00(-4.5,29) |
| Step length (cm) | 0.3 | 1.6 | 12.64(1.97) | 11.76(1.96) | NS |
| Step width (cm) | 0.5* | 1.6 | 12.3(2.38) | 12.7(2.23) | NS |
| **Spatial And Temporal Gait variables** while performing **Closed loop tacking task** | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
| Single Support time (ms) | 0.5* | 1.2 | 370.9(57.5) | 355.15(48.4) | NS |
| Swing time (ms) | 0.6* | 1.3 | 401.2(70.6) | 389.3(53.3) | NS |
| Cycle time (ms) | 0.5* | 2.4 | 657.5(98.78) | 695.7(104.5) | NS |
| Step length (cm) | 0.6* | 1.2 | 12.67(2.18) | 12.92(1.61) | NS |
| Step width (cm) | 0.5* | 1.5 | 12.1(2.17) | 11.6(1.96) | NS |

Significant correlation* ($p < 0.05$); NS= Not Significant

**Table 3c:** Results of statistical analysis, ICC scores, SEM and t statistics for the spatial and temporal gait parameters during walking and performing the two cognitive game task

| **Spatial And Temporal Gait variables** while performing **Simple cognitive game task** | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
|---|---|---|---|---|---|
| Single Support time (ms) | 0.5* | 1.3 | 380.9(61.5) | 385.15(53.5) | NS |
| Swing time (ms) | 0.5* | 1.2 | 402.7(61.8) | 389.6(66.0) | NS |
| Cycle time (ms) | 0.5* | 2.2 | 663.6(106.06) | 677.3(112.4) | NS |
| Step length (cm) | 0.6* | 1.2 | 10.6(2.14) | 11.8(2.05) | NS |
| Step width (cm) | 0.6* | 1.4 | 11.4(1.8) | 11.30(2.4) | NS |
| **Spatial And Temporal Gait variables** while performing **Moderate cognitive game task** | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
| Single Support time (ms) | 0.5* | 1.3 | 365.75(54.5) | 386.3(56.6) | NS |
| Swing time (ms) | 0.5* | 1.2 | 281.5(60) | 280.3(43.03) | NS |
| Cycle time (ms) | 0.5* | 2.2 | 686.9(103.03) | 700.9(82.7) | NS |
| Step length (cm) | 0.6* | 1.2 | 10.60(2.06) | 10.64(1.74) | NS |
| Step width (cm) | 0.6* | 1.4 | 12.3(2.38) | 11.6(2.17) | NS |

Significant correlation* ($p < 0.05$); NS= Not Significant

Table 4 represents Test retest group means; standard deviations; ICC scores, SEM and t statistics for the average of the variance (RMS) during normal walking and walking while performing the visual tasks. The reliability score for trunk ML angular velocity (i.e. average of the variance) during normal walking and walking while performing the two cognitive game tasks were low, whereas, during open and closed loop tracking condition it was moderate.

During normal walking the SEM was observed to be 56.25% whereas during open loop and closed loop tracking conditions it decreased to 43% and 25% respectively, and during simple and moderate game tasks it was 36% and 33% respectively. This shows that as the visual task load was increased there was decrease in the trunk movements while walking. ICC scores increased when participants performed the visual tasks while walking as compared to normal walking. SEM scores decreased as the task load was increased.

**Table 4:** Results of statistical analysis, ICC scores, SEM and t statistics for the average of the variance (RMS) during normal walking and walking while performing the visual tasks

| **Trunk Angular Velocity** (degrees/ second) | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
|---|---|---|---|---|---|
| Normal Walking | 0.4* | 0.09 | 0.19(0.16) | 0.12(0.068) | NS |
| Open loop | 0.6* | 0.06 | 0.17(0.13) | 0.1(0.02) | NS |
| Closed loop | 0.5* | 0.02 | 0.07(0.14) | 0.102(0.078) | NS |
| Simple game task | 0.3* | 0.05 | 0.12(0.17) | 0.14(0.09) | NS |
| Moderate game task | 0.4* | 0.04 | 0.11(0.19) | 0.12(0.16) | NS |

Significant correlation* ($p < 0.05$); NS= Not Significant

### 5.1.3 Visual Tracking Task

Table 5 represents Test retest group means; standard deviations; ICC scores, SEM and t-statistics for COD of two tracking tasks performed during standing on the sponge surface and while walking on the treadmill. ICC scores for COD ranged from moderate to high. As the physical load was increased ICC decreased and SEM increased. The t-test showed no significant differences in the test retest COD group means when tracking tasks were performed while standing or walking.

When tracking tasks were performed while standing on the sponge, the open loop COD had a high reliability score, whereas, the closed loop COD had moderate reliability score. When tracking tasks were performed while walking on the treadmill, the open loop COD as well as the closed loop COD had a moderate reliability score.

SEM scores for open loop and closed loop tracking during standing were observed to be 11% and 12% respectively. When open loop and closed loop tracking tasks were performed while walking, the SEM scores were observed to be 33% and 16% respectively. This shows that as the physical load was increased the SEM also increased.

**Table 5:** Results of statistical analysis, ICC scores, SEM and t statistics for COD of two tracking tasks performed during standing on sponge surface and while walking on treadmill.

| Tracking task Performance (**COD**) while standing on **Sponge Surface** | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
|---|---|---|---|---|---|
| Open Loop | 0.7* | 0.08 | 0.70(0.14) | 0.69(0.17) | NS |
| Closed Loop | 0.6* | 0.09 | 0.80(0.09) | 0.83(0.08) | NS |
| Tracking task Performance (**COD**) while **Walking** | ICC | SEM | Mean± SD (test1) | Mean± SD (test2) | p-value (t-score; df) |
| Open Loop | 0.5* | 0.2 | 0.618(0.22) | 0.537(0.23) | NS |
| Closed Loop | 0.6* | 0.1 | 0.62(0.19) | 0.672(0.18) | NS |

Significant correlation* (p < 0.05); NS= Not Significant

### 5.1.4 Cognitive game task

Table 6 represents the Test retest group means; standard deviations; ICC scores, SEM and t-statistics for the cognitive game task performance measures (Success Rate, Response time and Execution time) during standing on the sponge surface and while walking on the treadmill.

ICC scores ranged from moderate to high and they decreased as the task load was increased. SEM scores increased when there was an increase in the task load. The t-test showed no significant differences in the test retest group means for all the performance measures.

Success rate during standing as well as while walking had moderate reliability scores. Response time while standing on the sponge had a high reliability score, whereas, during walking it was observed to have a moderate reliability score. Execution time during standing as well as while walking had moderate reliability scores.

The SEM for Success rate ranged from 3% during standing on the sponge to 4% while walking. For response time and execution time the SEM scores ranged from 6% and 12% while standing on the sponge to 8% and 13% while walking, respectively. This showed that as the physical load was increased there was an increase in the SEM scores for the cognitive game tasks.

**Table 6:** Results of statistical analysis, ICC scores, SEM and t statistics for cognitive game task performance measures (Success Rate, Response time and Execution time) during standing on sponge surface and while walking on treadmill.

| **Sponge Surface Cognitive game task performances** | ICC | SEM | Test 1 Mean(SD) | Test 2 Mean(SD) | p-value (t-score; df) |
|---|---|---|---|---|---|
| Success Rate (%) | 0.5* | 2.5 | 86.16(6.32) | 92.93(3.53) | NS |
| Response time (ms) | 0.7* | 0.03 | 0.495(0.054) | 0.499(0.062) | NS |
| Execution time (ms) | 0.6* | 0.05 | 0.49(0.088) | 0.48(0.096) | NS |
| **Cognitive game task performances** while **Walking** | ICC | SEM | Mean± SD (test1) | Mean± SD (test2) | p-value (t-score; df) |
| Success Rate (%) | 0.6* | 3.5 | 84.63(6.73) | 90.46(4.79) | 0.001(-3.7,29) |
| Response time (ms) | 0.6* | 0.04 | 0.5(0.06) | 0.477(0.056) | NS |
| Execution time (ms) | 0.5* | 0.06 | 0.50(0.072) | 0.51(0.09) | NS |

Significant correlation*p<0.05; NS= Not Significant

## *5.2 Construct Validity*

### 5.2.1 Effects of visual task conditions on standing balance (COP excursions)

Typical plots of COP excursions in AP and ML directions for individual participant performing different tasks while standing on fixed and sponge surface are presented in Figure 13. COP traces were offset to the value of zero for display purposes. The left panel represents the COP excursions while standing on fixed surface and performing the following tasks: eyes open, eyes closed, tracking and cognitive game tasks. The right panel represents the COP excursions while standing on sponge surface and performing the same tasks. The COP excursions were remarkably increased when there was an increase in the visual task load while standing on the sponge surface as compared to the fixed surface. Amongst all the tasks performed while standing on the fixed and sponge surface, COP excursions were significantly increased during eyes closed condition (i.e. In AP it was observed to be 5.09 cm, whereas, in ML direction it was observed to be 3.8 cm). Over 13.33% of the total sample population experienced loss of balance during eyes closed condition on sponge surface.

**Figure 13**: COP excursions in AP and ML directions for individual participant during standing on fixed and sponge surface while performing various tasks

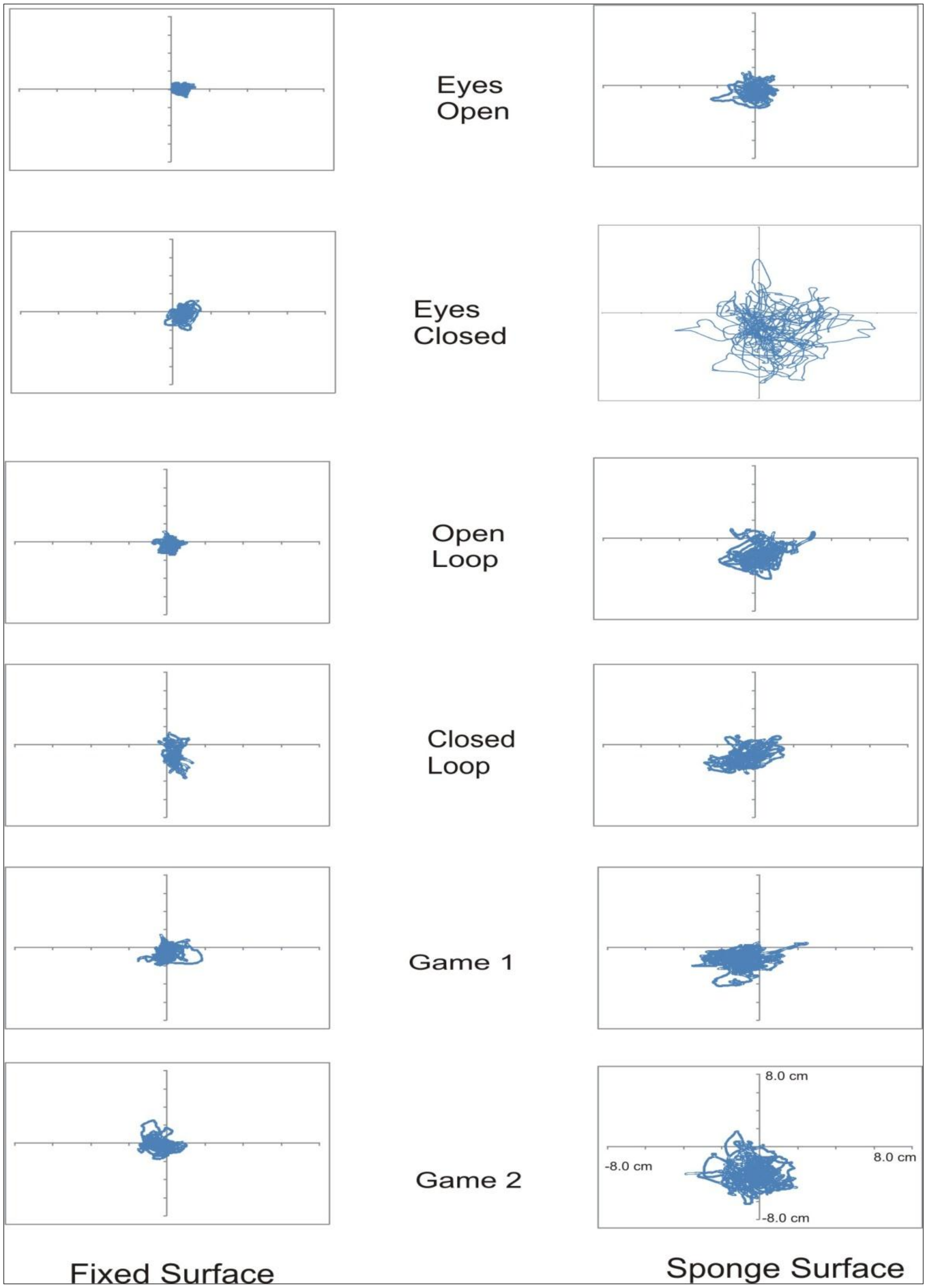
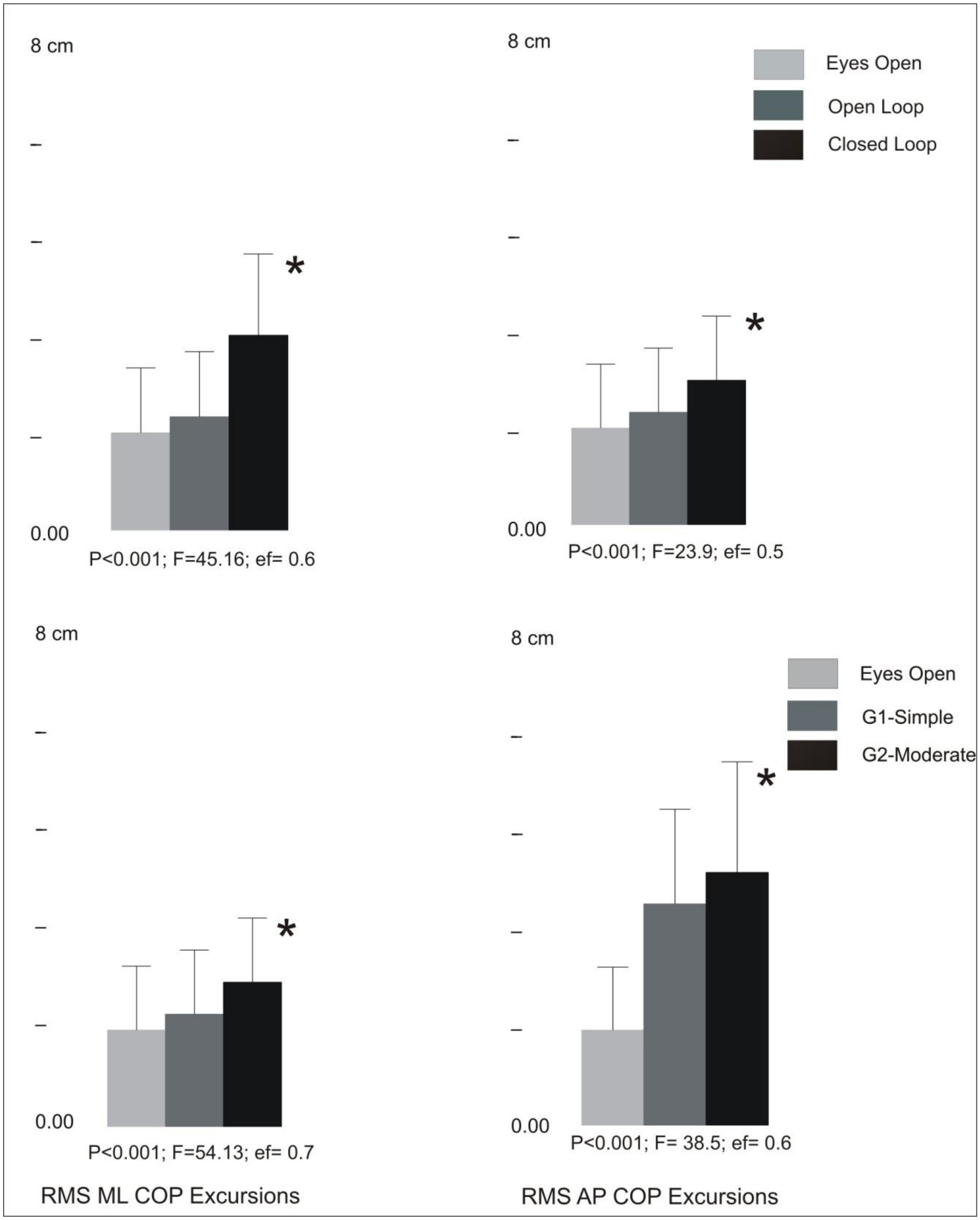


Figure 14 represents the group means, standard deviations and statistical results for the COP excursions in AP and ML directions during stand alone and standing while performing the visual tasks (tracking and cognitive game tasks). COP excursions were observed to be increased as the visual tasks were performed. A significant increase in the COP excursions in AP and ML directions was observed while performing the open loop and closed loop tracking tasks as compared to stand alone. Pair wise comparison revealed that significant increase in the COP excursions were more during the open loop task as compared to the closed loop. Also, during the simple and moderate game task a significant increase in the COP excursions was observed as compared to stand alone. There was no significant difference in the COP excursions when simple and moderate game tasks were compared.

The effect size which is the estimated magnitude of the relationship between the variables was also calculated. The observed effect size for the COP excursion in ML during tracking tasks was $np^2= 0.6$, whereas for the cognitive game task performance, it was $np^2= 0.7$. For COP excursions in AP the observed effect size for tracking tasks was $np^2= 0.5$ whereas during cognitive game tasks it was $np^2=0.6$. Larger the effect size greater is the effect of one condition on the variable. Thus cognitive game tasks overall had larger effect size which means the COP excursions were more during these tasks as compared to tracking tasks.

**Figure 14:** Group means and standard deviation for COP excursions during stand alone and standing while performing visual tasks (tracking and cognitive game tasks).



Significant* $p<0.05$

### 5.2.2 Effects of increase in physical and visual task load on standing balance

See Table 7a and 7b for the statistical results for the interaction effects of increase in the visual task load and physical load (i.e. standing on fixed and sponge surface) on COP excursions in AP and ML directions. Two way ANOVA was performed to examine the interaction effect of increase in physical as well as visual task load. A significant interaction effect was observed for RMS amplitude of COP excursion in ML direction during cognitive game task performance. The observed effect size during cognitive game task performance was 0.2.

**Table 7a** Effect of increased physical and visual task load (tracking tasks) on RMS COP excursions in AP and ML direction

| Variables | Tracking Task Load | Physical Load | Interaction |
|---|---|---|---|
| Root Mean Square ML (cm) | $p < 0.01$<br>$F = 31.641\ (2, 27)$<br>$n_p^2 = 0.4$ | $p < 0.001$<br>$F = 20.96\ (2, 27)$<br>$n_p^2 = 0.3$ | NS |
| Root Mean Square AP (cm) | $p < 0.001$<br>$F = 17.3\ (2, 27)$<br>$n_p^2 = 0.3$ | $p < 0.001$<br>$F = 16.3\ (2, 27)$<br>$n_p^2 = 0.2$ | NS |

(NS: Not Significant; $n_p^2$= Effect size)

**Table 7b** Effect of increased physical and visual task load (cognitive game task) on RMS COP excursions in AP and ML direction

| Variables | Cognitive Game Task Load | Physical Load | Interaction |
|---|---|---|---|
| Root Mean Square ML (cm) | $p < 0.001$<br>$F = 24.63\ (2, 27)$<br>$n_p^2 = 0.3$ | $p < 0.001$<br>$F = 19.05\ (2,27)$<br>$n_p^2 = 0.25$ | $p = 0.01$<br>$F = 4.44\ (2, 27)$<br>$n_p^2 = 0.2$ |
| Root Mean Square AP (cm) | $p < 0.01$<br>$F = 31.641\ (2, 27)$<br>$n_p^2 = 0.4$ | $p < 0.001$<br>$F = 20.96\ (2, 27)$<br>$n_p^2 = 0.3$ | NS |

(NS: Not Significant; $n_p^2$= Effect size)

### 5.2.3 Spatial and Temporal Gait Variables

#### 5.2.3.1 Effects of visual task conditions (tracking and cognitive game tasks) on spatial and temporal gait variables

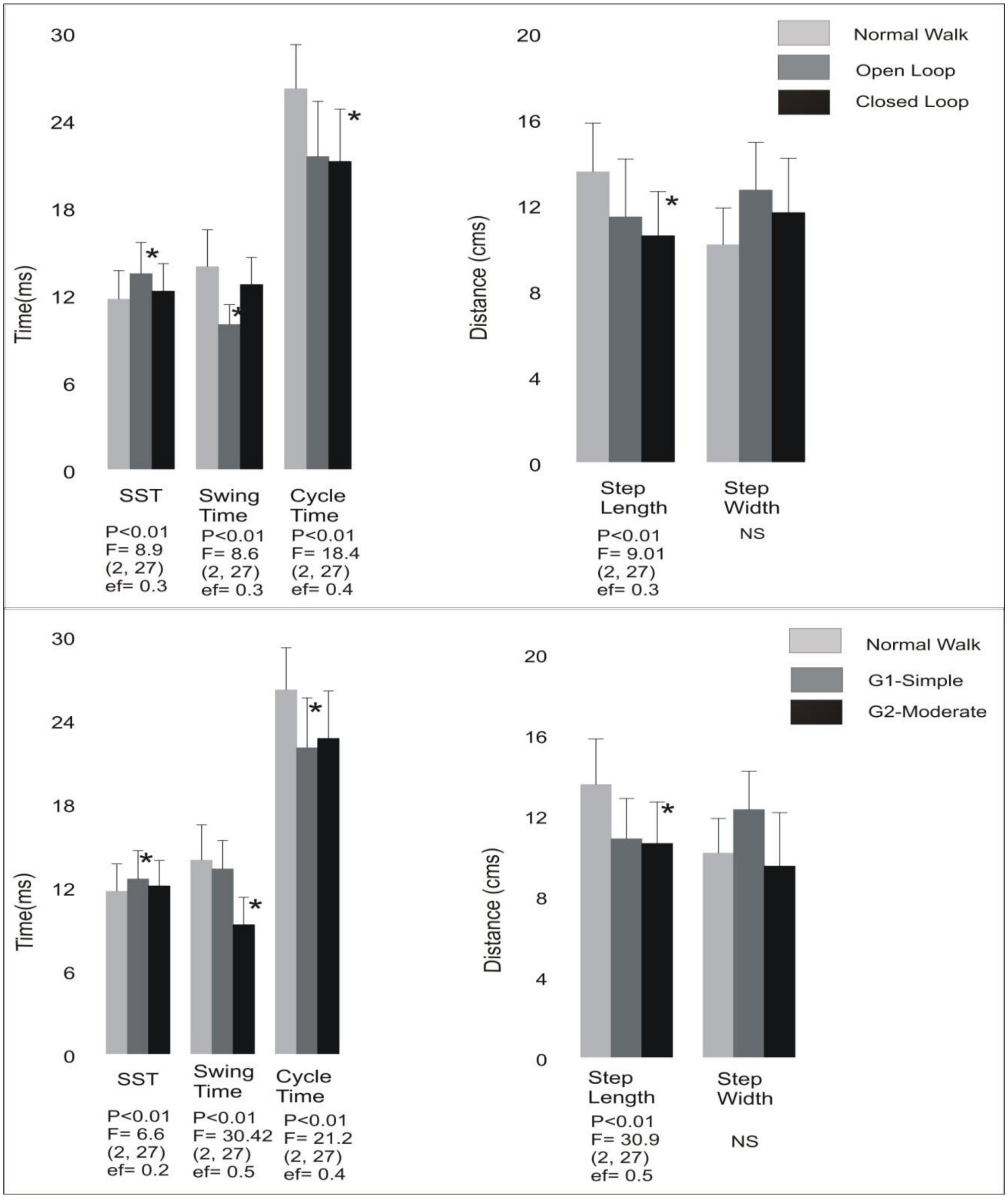
Figure 15 shows the group means, standard deviations and statistical results for the average values of spatial and temporal gait parameters during normal and dual-task walking (tracking and cognitive game tasks). Group means and standard deviations for spatial and temporal gait variables during normal walking varied from those while performing tracking and cognitive game tasks. Group means for few variables increased whereas for others it decreased as the visual task load was increased. Single support time was observed to be increased while performing both tacking and cognitive game tasks as compared to normal walking. Swing time and Cycle time on the other hand was observed to decrease while performing both tracking and cognitive game tasks when compared to normal walking. Step length and step width were increased during open and closed loop tracking and while moderate game task condition, but decreased during simple game task condition. This shows that as the visual task load was increased while walking, spatial parameters tend to increase and temporal parameters tend to decrease.

A significant increase in the average value of Single Support Time (SST) was observed while performing the tracking tasks as compared to normal walking ($p<0.01$). A significant decrease in average value of swing time, cycle time and step length was observed during tracking conditions as compared to normal walking ($p<0.01$). Pair wise comparison revealed that the closed loop tracking has a larger effect on the spatial and temporal gait parameters as compared to open loop.

When the cognitive game tasks were performed a significant increase in the average value of SST was observed while dual tasking as compared to normal walk ($p < 0.0001$). And a significant decrease in the average values of swing time ($p=0.001$), cycle time ($p=0.001$) and step length ($p=0.001$) was observed. The average value of step width was not significantly different during any of the dual-tasks performances (tracking and cognitive game) when compared to normal walking. Pair wise comparison revealed that there was a significant difference in the spatial and temporal gait variables during simple and moderate game task conditions. It was observed that the simple game task had a larger effect on Single Support Time, Cycle time and step length, whereas moderate game task had a larger effect on swing time.

The observed effect size for the spatial and temporal gait variables during tracking task performances while walking are as follows: SST= 0.3; Swing time= 0.3; Cycle time= 0.4; Step length= 0.3. When the cognitive game tasks were performed following were the observed effect sizes: SST= 0.2; Swing time= 0.5; Cycle time= 0.4; Step length= 0.5. Effect sizes during the cognitive game task performances were larger which means cognitive game tasks had a higher impact on the spatial and temporal gait variables.

**Figure 15:** Group means and standard deviations for the spatial and temporal gait parameters recorded during normal and dual-task (tracking and cognitive game tasks) walking.



Significant* p<0.05; NS= Not Significant

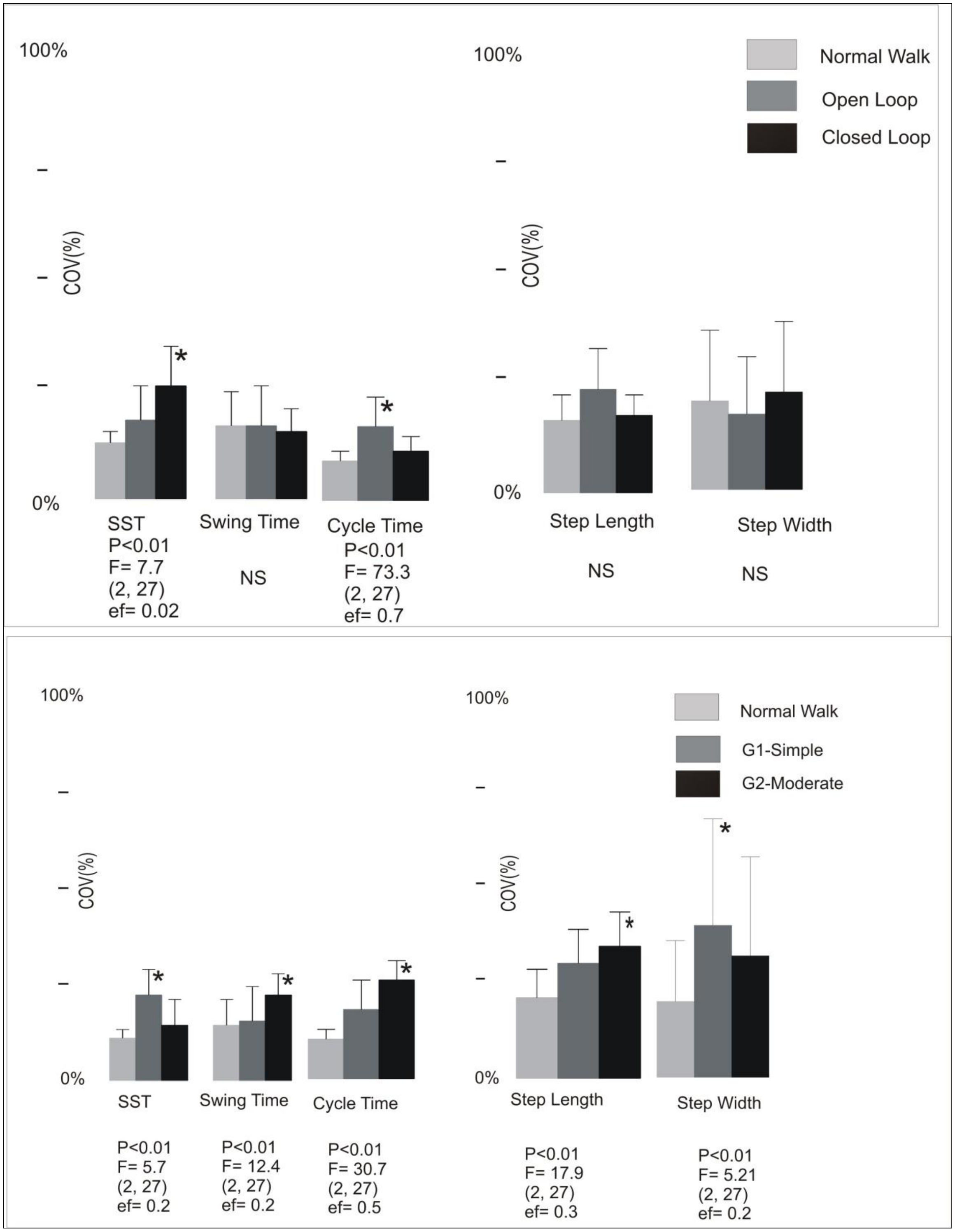
#### 5.2.3.2 Effects of visual tasks conditions (tracking and cognitive game task) on spatial and temporal gait variability

Figure 16 represents the COV (%) and the statistical results for the spatial and temporal gait parameters during normal and dual-task walking (tracking and cognitive game task). The variability in the spatial and temporal gait variables increased as the visual tasks were performed while walking.

A significant increase in the single support time (COV) was observed during tracking conditions as compared to normal walking. ($p<0.001$) No significant change was observed in swing time (COV) during tracking conditions as compared to normal walking. A significant decrease in the cycle time (COV) was observed during tracking conditions as compared to normal walking ($p< 0.001$). No significant effect of the tracking task performance was observed on the step length (COV) as compared to normal walking. No significant effect of tracking tasks was observed on step width (COV) as compared to normal walking.  Pair wise comparison revealed that closed loop tracking had a larger effect on Single Support Time and Cycle time as compared to open loop.

During the cognitive game task performances, a significant increase in the variability of single support time, swing time, and step width was observed as compared to normal walk (SST: $p= 0.005$, swing time: $p< 0.001$, step width: $p<0.001$). A significant decrease in the cycle time and step length variability was observed ($p< 0.001$). The observed effect sizes for the spatial and temporal gait variables while performing the tracking tasks are as follows: SST= 0.02; Cycle time= 0.7; and Step length= 0.05. The observed effect sizes for the spatial and temporal gait variables while performing cognitive game tasks are as follows: SST= 0.2; Swing time= 0.3; Cycle time= 0.5; Step length= 0.3 and Step width 0.2. Pair wise comparison revealed that simple game task had a larger effect on Single Support time, Cycle time, Step Length and Step width variability whereas moderate game task had a larger effect on Swing time variability. Thus cognitive game tasks had a higher impact on all the spatial and temporal gait variables except for cycle time.

**Figure 16:** Spatial and Temporal gait variability (statistical results) during normal and dual-task (tracking and cognitive game task) walking.



Significant* p<0.05; NS= Not Significant

Figure 17 represents the overlay of the segmented trajectories during normal walking and walking while performing tracking and cognitive game tasks of an individual participant. Interestingly, the trajectories of trunk angular velocity ML during tracking and cognitive game task performances clustered together as compared to normal walking. This shows that while performing the visual tasks participants developed a protective strategy to maintain balance while walking i.e. decreasing the excess movements of the trunk.

**Figure 17:** Overlay of the segmented trajectories

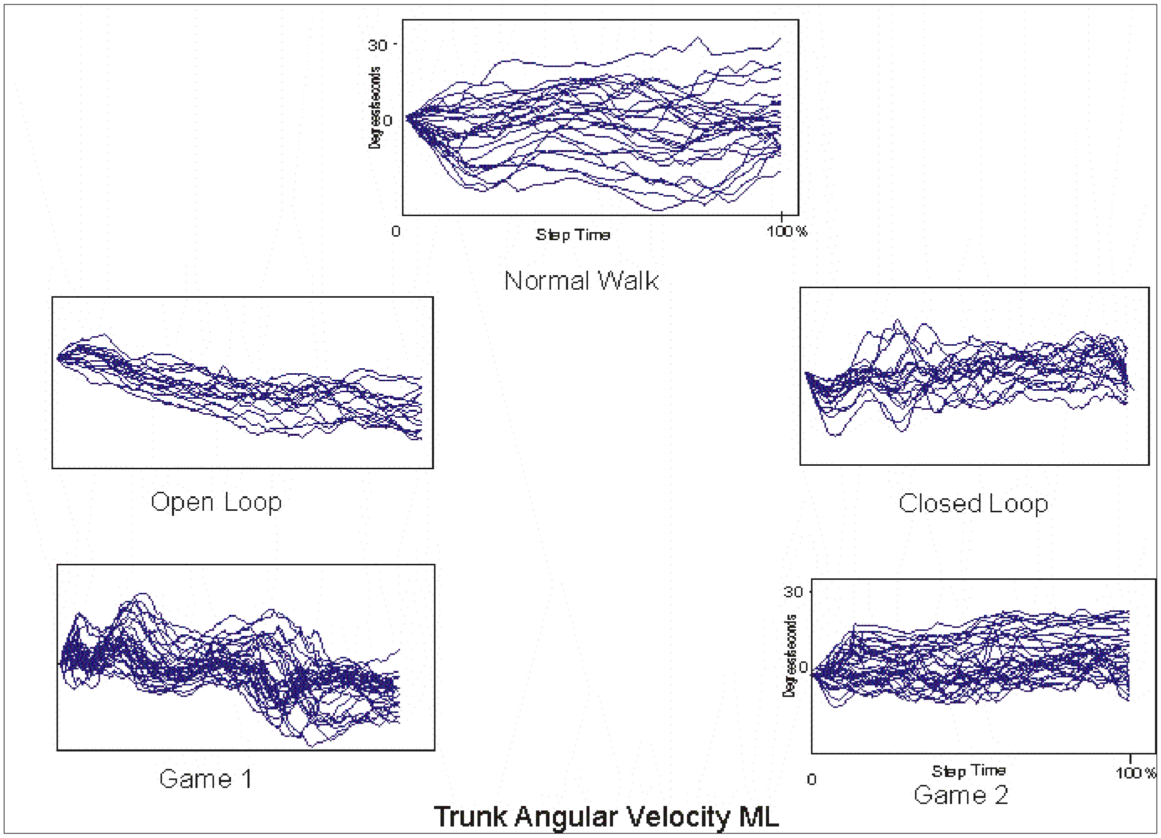
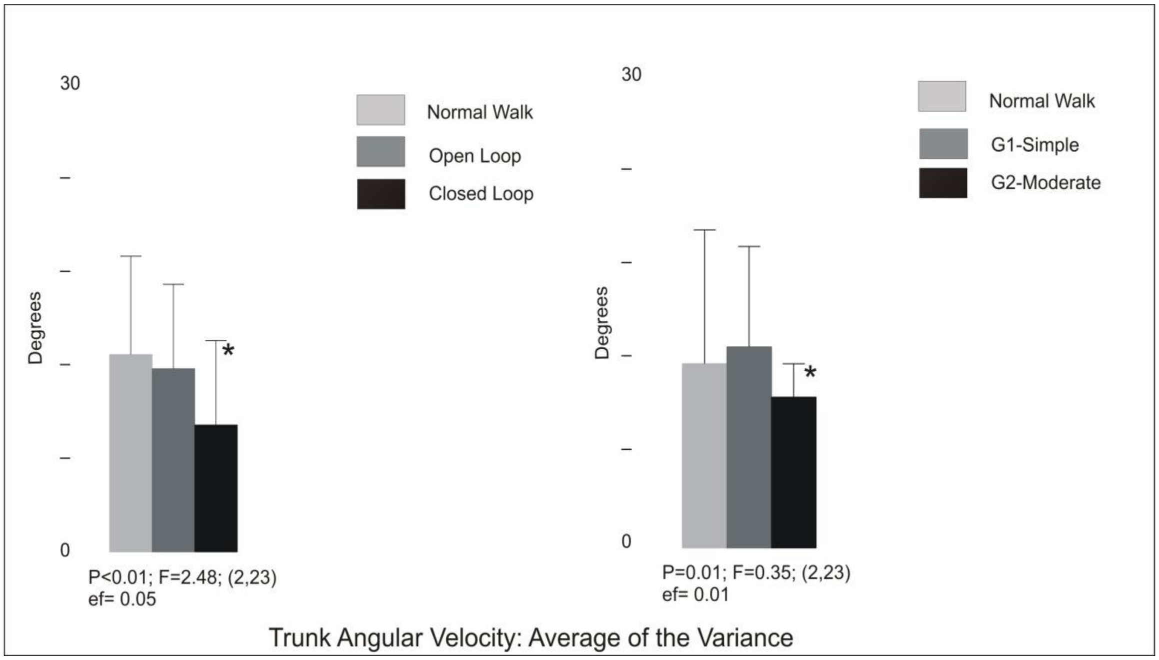


Figure 18 represents the average of the variance for trunk ML angular velocity, standard deviation and statistical results during normal walking and walking while performing the visual tasks (tracking and cognitive game tasks) of an individual participant. A significant decrease in the average of the variance during tracking condition was observed as compared to normal walking. During cognitive game tasks, a significant decrease in the average of the variance in trunk ML angular velocity was observed as compared to normal walking. Pair wise comparison revealed that closed loop tracking and moderate game task had a larger effect on decreasing the trunk angular velocity as compared to open loop tracking and simple game task condition. The observed effect sizes during tracking and cognitive game conditions were 0.05 and 0.01 respectively. This means tracking tasks had a greater impact on average of variance of trunk angular velocity in ML than the cognitive game tasks.

**Figure 18:** Group means, standard deviations and statistical results for the Average of the variance for trunk angular velocity



Significant* $p<0.05$

### 5.2.3.3 Effect of increased physical load on tracking task performance

Figure 19 represents a typical individual participant's performance of the two tracking tasks while standing on the fixed and sponge surface and while walking. The upper panel represents the sinusoidal trajectories for the open loop condition during standing on the fixed surface, sponge surface and while walking whereas the lower panel represents the sinusoidal trajectories for closed loop conditions. The sinusoidal trajectory for both open and closed loop conditions remarkably dispersed when the tracking tasks were performed while walking as compared to standing on fixed surface. This shows that the quality of the movement trajectory (in comparison to the reference trajectory) measured using COD was decreased during walking as compared to standing on the fixed surface.

**Figure 19**: Individual participant performance of the two tracking tasks while standing on fixed and sponge surface and while walking

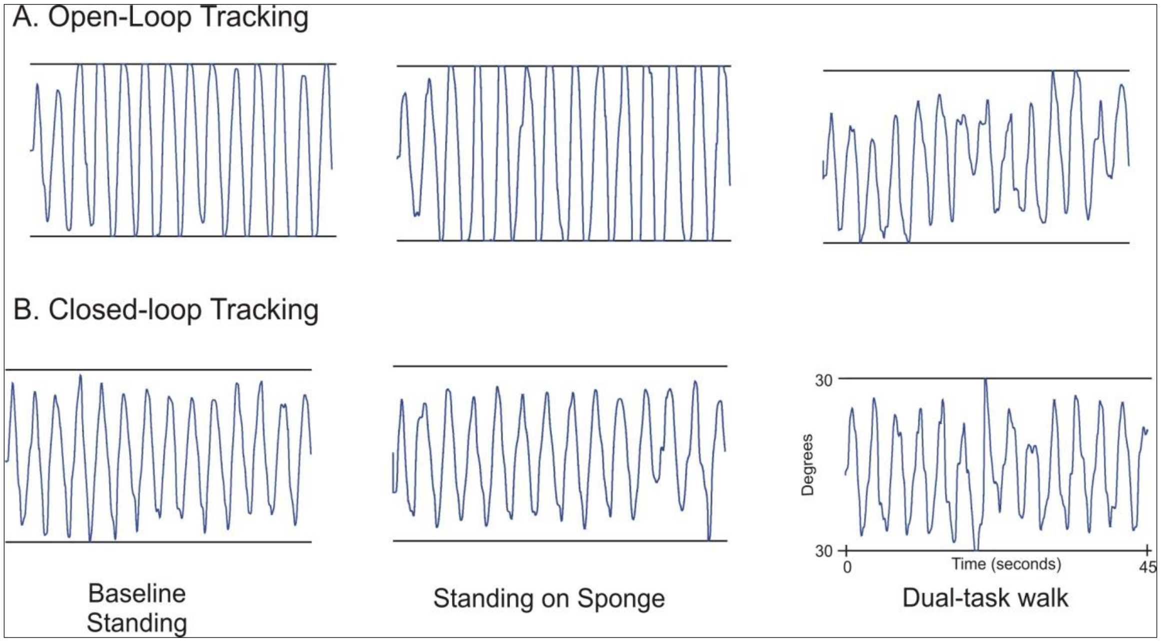
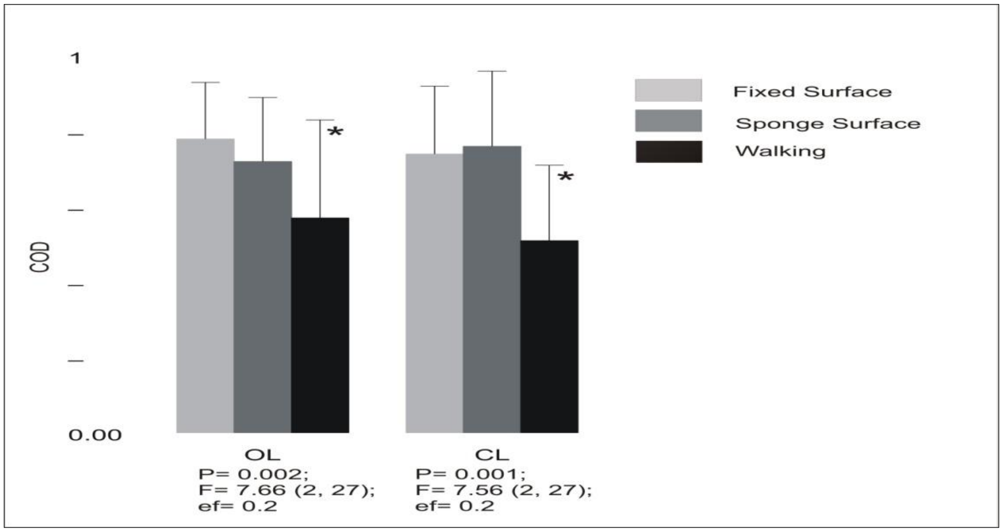


Figure 20 represents the group means, standard deviations and statistical results of COD of open and closed loop tracking tasks performed during standing on sponge surface and while walking. The Open loop COD during standing on fixed and sponge surface was observed to be good (ranging from 0.7 to 0.8), but while walking it was fair (0.6). Thus when the physical load was increased COD decreased. Table 11shows the statistical values for the effects of increase in physical load on tracking task performances. While performing Open loop tracking task, a significant decrease of COD was observed when physical load was increased from standing on the fixed surface to walking (p= 0.002) During standing on the fixed and sponge surface COD for open loop tracking was observed to be 0.7, whereas while walking it was 0.5. Similarly a significant decrease in COD was observed for the closed loop tracking task when the physical load was increased. (Standing on the fixed surface =0.7; sponge surface=0.6; walking= 0.4) Bonferroni correction pair wise comparison showed a significant decrease in the visual task performance while walking on treadmill as compared to standing on fixed and sponge surface. The effect sizes observed for the Open and closed loop tracking COD was 0.2 respectively. This shows that increase in physical load had a similar effect on performance of both tracking tasks.

**Figure 20**: Group means, standard deviations and statistical results for visual task during standing on fixed surface, sponge surface and while walking.

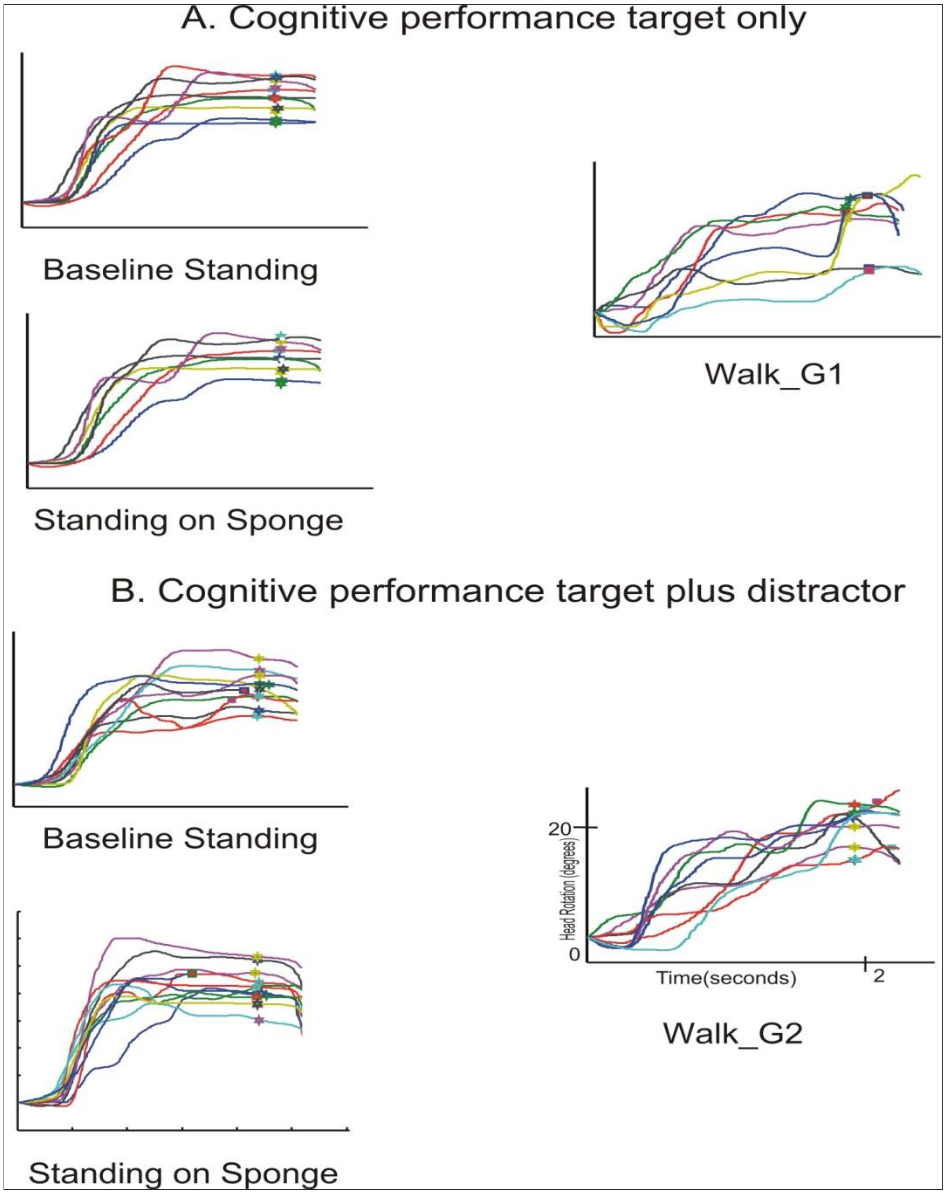


Significant* $p<0.05$; OL: Open Loop; CL: Closed Loop; COD: Coefficient of Determination.

#### 5.2.3.4 Effects of increased physical load on cognitive game task performances

Figure 21 below represents an individual participant performance of the simple and moderate cognitive game tasks during standing on the fixed surface, sponge surface and while walking. Panel A represents the simple cognitive game task performances whereas Panel B represents the moderate cognitive game task performances. During standing on fixed surface, the movement trajectories for both simple and moderate cognitive game task had a regular pattern with the regular onset period and the plateau phase. This means that the participant took less time to move the paddle as the target appeared on the screen (response time) and more time was spent to complete the task (execution time). On the other hand while walking and performing the two cognitive tasks, the movement trajectories were irregular and scattered. Hence increase in the response time and execution time.

**Figure 21** Cognitive Game Task performances during various physical loads

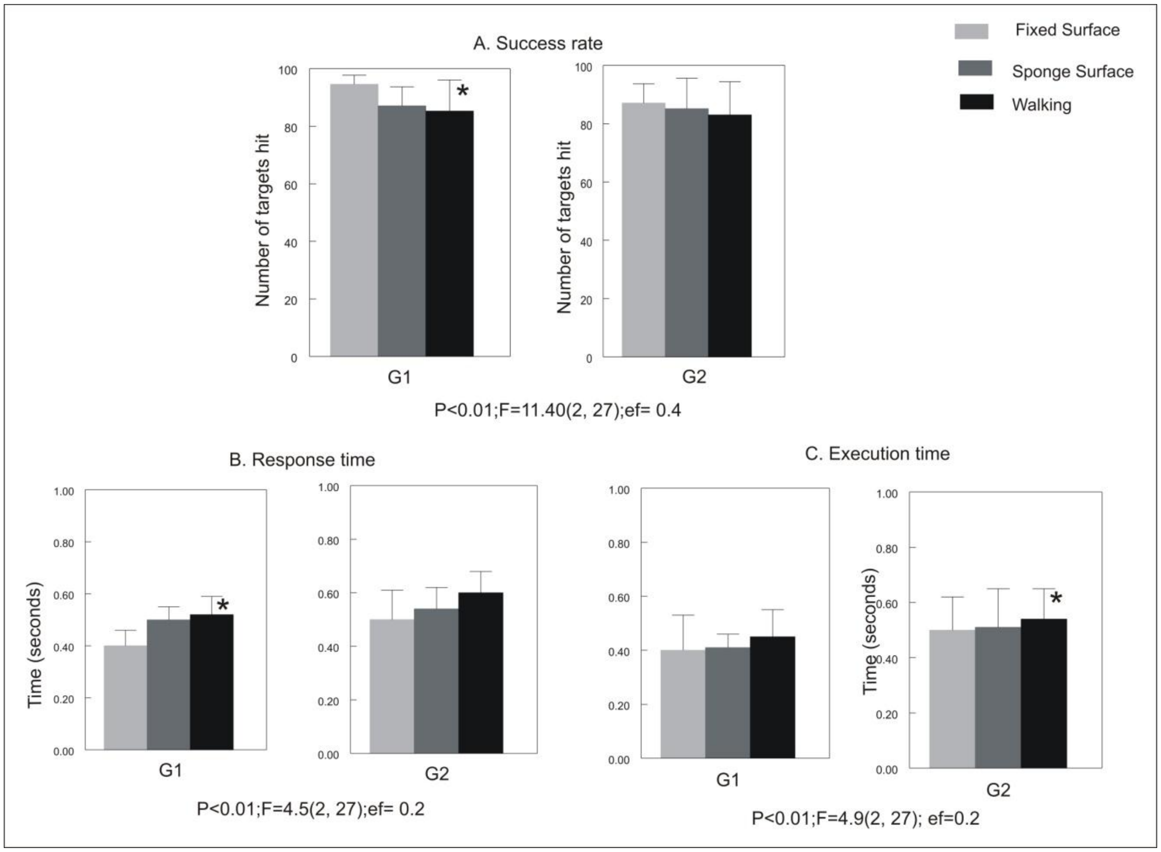


G1: Simple game task; G2: Moderate Game task.

Figure 22 shows the group means, standard deviation and statistical results for cognitive game task performance measures during simple and moderate game task performance while standing on fixed and sponge surface and while walking. A significant decrease in the success rate was observed while performing the task during walking as compared to standing on fixed and sponge surface ($p< 0.001$). Success rate during standing on fixed surface was 90% whereas on sponge surface it was 87% and while walking it was 84%. A significant increase in the response time was observed while performing the task during walking as compared to standing on fixed and sponge surface ($p= 0.01$). Response time during standing on the fixed surface was 0.4 s, on the sponge surface it was 0.5 s whereas while walking it was 0.7s. Similarly, a significant increase in the execution time was observed while performing the task during walking as compared to standing on fixed and sponge surface ($p= 0.01$).

The effect sizes observed for Success rate, Response time and Execution time were 0.4, 0.2 and 0.2 respectively. This means that Success rate was more affected than response time and execution time as there was increase in the physical load. Bonferroni correction pair wise comparison showed a significant decrease in the success rate and a significant increase in response time and execution time when the task were performed while walking on the treadmill as compared to standing on fixed and sponge surface ($p< 0.05$).

**Figure 22:** Group means and standard deviation and statistical results for cognitive game task performance measures during simple and moderate game task performance while standing on fixed and sponge surface and while walking.



A. Success rate

P<0.01;F=11.40(2, 27);ef= 0.4

B. Response time

P<0.01;F=4.5(2, 27);ef= 0.2

C. Execution time

P<0.01;F=4.9(2, 27); ef=0.2

Significant* p<0.05; G1: Simple game task; G2: Moderate game task.

## Chapter 6: Discussion

The purpose of the present study was to validate the TRP protocol measures that assessed balance (standing and walking), stability (body sway parameters), visual tracking and cognitive game task performances in healthy, community dwelling older adults. Relative reliability of the tool measures was assessed and interpreted with the help of ICC scores whereas Absolute reliability was evaluated with the help of Standard Error of Measurement (SEM). It was observed that the overall test retest reliability of most of the tool measures ranged from moderate to high with a few exceptions that had low ICC scores. An increase in visual task load significantly decreased standing balance performance. Locomotor skills and stability during walking was also decreased when visual task load was increased. When there was an increase in physical load from standing on fixed surface to sponge surface to walking there was a significant decrease in the visual task performances. We also observed a significant interaction effect on COP excursions in the ML direction when there was increase in physical as well as visual task load in standing.

### 6.1 Test retest Reliability

### 6.1.1 Standing Balance

Studies use COP excursions recorded using force platform to examine standing balance while performing tasks from SOT or CTSIB. Excellent tests retest reliability scores for the COP excursions in ML and AP directions were observed during these tasks. But, as the threat to balance or the task complexity was increased the reliability scores were observed to decrease. Similar findings were seen in the present study.

Pang et al., (2011) included 92 young and 73 old adults (mean age 42.4± 18.4 years) in their study to examine the test retest reliability and minimal detectable change (MDC) during head shake SOT task under conditions 2 and 5. Participants who performed horizontal head movements during SOT conditions 2 and 5. It was observed that during both head shake SOT (HS-SOT) conditions young adults had a high reliability score of 0.8 and 0.7 respectively. But older adults had a moderate reliability score of 0.6 and 0.5. The minimal detectable error increased as the task complexity was increased. For young adults during HS-SOT condition 2 the MDC was 2.7 (SEM = 1.0) whereas during HS-SOT condition 5 it was observed to be 16.2 (SEM= 6). And for older adults it changed from being 3.6 (SEM = 1.3) during HS-SOT condition 2 to 22.7 (SEM= 8.4) during HS-SOT condition 5. As the ICC ranged from high to moderate it was observed that as the task complexity increased ICC decreased and SEM increased. The present study extends the scope of using the horizontal head rotations by instructing the participants to focus on the moving object and perform head rotations at a self-selected frequency. Thus in the present study by increasing the task complexity and challenging the three sensory systems (visual, vestibular and somatosensory) causing increased threat to balance, we observed a decrease in the ICC scores from high to moderate.

Lin et al., (2008) examined the within day and between day reliability of the COP excursions when 16 young adults and 16 older adults were asked to perform eyes closed condition while standing on fixed surface. A force platform (AMTI) was used to record the COP excursions and RMS of the COP excursions was calculated. They observed high reliability scores for both young and older adults for between and within day reliability tests for performing eyes closed condition while standing on fixed surface. The ICC score for within day reliability for young adults was 0.8 (SEM= 0.6), whereas for older adults it was 0.8 (SEM= 1.0). The between day reliability scores were as follows; for young adults the ICC score was 0.7 (SEM= 1.6) whereas for older adults it was 0.8 (SEM= 1.0). These results show that older adults stiffened their body to maintain balance and decrease the amount of sway during the task performance (head rotations) as compared to young adults who had a larger sway and were able to maintain their balance during the task performance. We evaluated the test retest reliability when various visual tasks were performed while standing on the sponge and not while standing on fixed surface only. This extends the above findings as there was increase in both threat to balance and visual task complexity.

Doyle et al., (2005) assessed the reliability scores and technical error of measurement (TEM) of thirty healthy young adults  (mean age 23± years) while performing the following tasks: 1) standing on the fixed surface with eyes open; 2) with eyes closed; 3) standing on the foam surface with eyes open and 4) with eyes closed. They observed following ICC scores: For COP AP excursions; condition 1: low ICC score of 0.4; condition 2: moderate ICC of 0.6; condition 3: low ICC of 0.3 and for condition 4: high ICC of 0.7. The observed TEM was as follows: condition 1: 0.3 (25%); condition 2: 0.8 (50%); condition 3: 0.6 (23%); condition 4: 4.25 (76%). For COP ML excursions following were the observed ICC scores; condition 1: high ICC of 0.5; condition 2: moderate ICC of 0.5; condition 3: moderate ICC of 0.5; and condition 4: moderate ICC of 0.6. The observed TEM was as follows; condition 1: 0.32 (41%); condition 2: 0.5 (59%); condition 3: 2.45 (90%); and condition 4: 4.61 (90%). An increase in the TEM can be observed when there was increase in task complexity. In this study a force platform is used to record the COP excursions in the AP and ML directions whereas in the present study a force mat placed on the top of the sponge was used to record the COP excursion. The use of force platform allows recording the COP excursions by placing the force plate on the sponge which detects the COP signals that are unaffected by the ground reactions forces. And unless there is no ground reaction forces acting on the foot pressure the actual COP excursions when the threat to balance is increased cannot be assessed. Also, the SEM calculated in the present study is lower than the TEM presented in the above study even when the task complexity was increased.

Swanenburg et al., (2008), included 37 community dwelling older adults (mean age 73± 6 years) to examine the test retest reliability of the COP excursions in AP and ML directions under following conditions: 1) standing on the fixed surface with eyes open; 2) standing while performing a counting backward task in steps of seven; 3) standing while looking at a grey colored cross one meter away from the standing position; and 4) standing on the fixed surface when vision was occluded using custom-made opaque goggles. They observed a high ICC scores for COP ML excursions during following conditions; Condition 1: 0.8, condition 2: 0.7, condition 3: 0.7, and condition 4: 0.8 respectively. For COP AP excursions they observed a moderate ICC scores; Condition 1: 0.5, condition: 2 0.5, condition 3: 0.6, and condition 4: 0.5 respectively. They did not calculate the SEM scores and hence the measurement error is unknown. The present study extends the use of COP excursions in AP and ML directions during various tracking and cognitive game task conditions while standing on sponge surface rather than just traditional eyes open and eyes closed standing tasks on fixed surface. In comparison to these findings we achieved moderate to high reliability scores when the visual task load was increased. Also, the observed SEM scores indicated less measurement error. This indicates that even though there was decrease in the ICC scores when task complexity was increased the results were consistent making the tool reliable. We used a force sensory mat which is inexpensive and can be easily operated instead of an expensive and heavy force platform.

Corriveau H et al., (2001) observed similar results for the COP excursion computed using force platform during eyes open and eyes closed conditions. Participants (n= 59; age= > 60 years; 45 participants were healthy whereas 14 were stroke patients) were asked to perform the tasks of eyes open and eyes closed while standing on force platform four times for 30 seconds each in one session. This was repeated after seven days and ICC scores were calculated. They obtained moderate ICC scores for the all the tasks performed in the study. (ICC: 0.5 to 0.6). Santos et al., (2008) included 12 healthy young adults aged 26.9 ± 4.7 years. They were asked to perform two tasks; standing on force plate with eyes open and then eyes closed. They observed a moderate reliability for COP RMS variable (ICC: 0.6) during eyes open condition where as poor ICC score during eyes closed conditions.

In the present study, COP was recorded using a force sensory mat which is easy to use, inexpensive, and portable unlike the SOT set up or heavy force plates. The present study extended the scope of using COP excursions to examine standing balance by assessing them during visual tracking and cognitive game task performances while standing on sponge surface. The tasks such as open loop and closed loop tracking included head rotations resulting in challenging the visual, vestibular and sensory system. The cognitive game tasks were also performed while standing on sponge surface which challenged the executive processing. The ICC scores obtained while performing eyes open and closed tasks were high but when the visual task load was increased and not eliminated COP excursions varied during test and retest causing a decrease in the ICC scores from high to moderate. Thus learning effect was reduced. The SEM score during eyes open and closed condition was lower as compared to those obtained during the visual task performances. It was highest during cognitive game task performances. This shows that while performing visual tasks participants tend to forget the planned strategy to maintain balance and thus balance gets challenged in an exclusive manner.

### 6.1.2 Spatial and Temporal Gait Parameters

Studies use spatial and temporal gait variables to assess the change in gait variability during normal walking and walking while performing dual-tasks. The reliability scores during normal walking ranged from moderate to high, Faude et al., (2012); Reid et al., (2005). Similar findings were observed in the present study. A study performed by Faude et al., (2012) examined the reliability of the spatial and temporal gait parameters (stride time, stride length and double support time) during normal walking on treadmill. They included 20 participants (age = 64.8±3.2 years) in the study. All the participants were asked to walk on the treadmill at a speed of 5 km/ hrs. They recorded 400 steps and were used for the analysis. The equipment used in this study is the one-dimensional ground reaction force measuring treadmill (Zebris Medical GmbH, FDM-T system, Isny, Germany). They observed a high ICC scores (> 0.7) for all the averaged gait variables during normal walking (Stride time, stride length, double support time).

A study performed by Reid et al., (2005) included 16 healthy adults age ranging from 28 to 53 years to evaluate the test re test reliability of the step time and step length using a motion capture system during normal walking. All the participants were asked to walk at a comfortable speed on a 6 m walkway and the data recorded from 5 steps was used to compute the variables. They observed an ICC score of 0.7 (high) for both step time and step length during normal walking.

These studies have similar findings to the present study but the instruments used for recording the data are either force platform embedded in treadmill or motion analysis system or 3D camera system. These instruments are costly, and they are not easily portable. Some of the instruments like motion analysis or 3d camera system require a laboratory setup and a qualified technician to operate it. On the other hand the instruments used in the present study includes just one force sensory array mat embedded underneath treadmill belt, and the data recording is just one button press which makes it easy to operate, as well as it is inexpensive and portable.

In the present study, we extended the scope of using spatial and temporal gait variables during dual tasking by assessing the test retest reliability of spatial and temporal gait parameters while performing visual tracking and cognitive game tasks. ICC scores were observed to decrease when the visual tasks were performed while walking as compared to normal walking. The SEM scores were increased while dual-task walking as compared to normal walking. This indicates that there was less learning effect and SEM percentages indicated that the tool measures had less measurement error and good repeatability in data recording. As the visual tasks were performed while walking gait variables during test re test had high SEM score indicating that there was less systemic bias.

The Average of the variance derived from the individual step data was used as the stability measure while normal walking and while dual-task walking. The reliability of this variable during both normal and dual-task walking (tracking and cognitive game task conditions) ranged from low to moderate.

Sheikh et al., (2010) examined the reliability of the inertial sensors (Fastrak, Polhemus, USA) similar to the one used in the present study to record the angular rotations of trunk during walking. They included 20 young adults (mean age 23.7 years) in the study. Participants were asked to walk over ground and the trunk angular rotations were recorded. They observed a good to excellent reliability of the angular rotation variable during normal walking (ICC 0.7 to 0.9). This is in contrast to the present study in which we observed low reliability score for normal walking. When the walking speed is controlled there is increased variability in the trunk movement resulting in low ICC scores. The SEM score was also observed to decrease during dual-task walking as compared to normal walking. This indicates that participants when walking while performing visual tasks use a planned strategy to avoid loss of balance. This indicates that the strategy might have resulted in decreased trunk movement thus increasing the measurement error and causing a learning effect. Also, these results suggest that the newly developed TRP tool can be used for treatment purposes in order to reduce the excessive trunk rotations thus resulting in good trunk control.

### 6.1.3 Visual Tracking Tasks

Head rotations while standing as well as while walking play an important role in day-to-day experiences. For example crossing a busy street, or reading the subtitles on the screen requires head movements while maintaining balance. A study performed by Kristjanson et al., (2001) examined the test re test reliability of head movement in a predictable manner using electromagnetic sensor. Twenty healthy young adults were recruited in the study. Participants were asked to rotate their head without any stimuli (left to right and vice versa) in standing. They performed this task twice with a between period of one week. The observed ICC score was low (0.3). In another study performed by Kristajanson et al., (2004) they used a slow moving object on the screen in a predictable pattern for head rotations in standing and then they obtained a test retest reliability of 0.7 for head rotations. Participants were provided with a target to focus on (cue) that resulted in smooth and repeated head rotations in similar manner thus reducing the measurement error. Pinsault et al., (2008) suggested that minimum of ten trials of a task is necessary to achieve a good ICC value of 0.5 to 0.8, Michiel et al., (2012) observed that, a good test retest reliability measures depend on the number of trials as well as on the nature of the task. They suggest that tasks involving head repositioning as well as head rotations had a reliability ranging from moderate to high (ICC: 0.5 to 0.8). They observed similar reliability scores irrespective of the task. The nature of task in the present study is very simple and easy to understand as it is built for the understanding of the older adults.

We extended the use of head rotations by assessing the quality of head movement using coefficient of determination (COD). The visual tracking tasks used in the present study forced the participants to foveate on the target as well as use their ocular reflexes to maintain their head rotations in sync to the target cursor movements. The ICC results showed that there was hardly any ceiling effect towards the tracking task performance. Along with this, the SEM percentages for COD for open and closed loop indicate a good repeatability and reliability. As the tasks performed during walking had higher SEM percentage it shows that the participants were not able to perform in a similar manner during the two test sessions.

### 6.1.4 Cognitive Game Tasks

Cognitive processing while standing as well as while walking is necessary to maintain balance. Penner et al., 2012, included 29 children (mean age 11.4 years ± 1.1 years) and 40 adults (mean age 25±5.85 years) in their study to examine the test retest reliability of the computerized Stroop test using three different versions. In the first version, participants while sitting were asked to name the color of the stimuli presented on the screen and the time was recorded. In the second version participants were presented with a sign of “X” with different colors and were instructed to respond the color of that “X” using the four color buttons provided. In the third version, participants had to decide as quickly as possible whether the color name printed in black was the same color of the stimulus. Participants repeated this for three trials on the same day. Participant’s response time were calculated and used for analyses. They observed that for condition 1 test retest reliability score were high (0.89), whereas for condition 2 it was moderate (0.6) but for condition 3 they observed a high correlation (0.8). As the difficulty in the task increased the reliability score decreased. Thus for condition two reliability decreased to moderate as compared to condition 1 and 3.

Hofheinz et al., (2010) examined the reliability of using TUG with dual-task (counting backwards) for the prediction of the risk of falls. They included 23 participants with age ranging from 60 to 87 years in the study. Participants were asked to perform counting backwards in threes from 100 while they performed TUG. The time taken to perform TUG, response time and the correct responses during the cognitive task performance were recorded. They observed high test retest reliability for the task measures when TUG with dual-task was performed (ICC score: 0.9). The study does not calculate the SEM scores and thus measurement error is unknown. Also, when there was increased task load while performing TUG, ICC remained constant with the reliability of the normal TUG score (High ICC of 0.9). This indicates that the difficulty of the cognitive task performed is not up to the level where it can affect the task performance or can decrease the learning effect. thus a cognitive task with different complexity levels as used in the present study are important to be used to decrease the learning effect or systemic bias and observe the actual effect of cognitive tasks load on test retest reliability scores.

Traditionally dual-task assessment paradigms have used simple cognitive tasks that do not involve visual motor system. Those tasks are capable of producing very limited outcomes (Herman T et al., 2010; Hobert et al., 2011; Al-Yahya et al., 2011). The visual spatial processing of object location or motion and their spatial relation with respect to the body and space are the key aspects of balance and locomotor skills. The cognitive tasks included in the present study required not only processing the object location but also the speed at which the object was falling. It also recorded the time taken to reach the hitting position and the manner of head rotation. The analysis method used in the present study allowed us to analyze not only the objective measures but also the process measures of the task performances. According to Weir et al., (2005), Batterham et al., (2013) and Adsaur et al., (2013), whenever there is a systematic bias or whenever there is a measurement error, the ICC scores decrease. In the present study success rate and execution time during standing as well as while walking had moderate ICC scores. This shows that when the physical load was increased there was no ceiling effect from the participant's side as well as there was very minimal measurement error during the data recording. In an attempt to avoid the ceiling effect the order of the game tasks used in the present study were randomized. SEM for these variables was observed to increase when the task was performed while walking. This can be the result of increase in the physical load of walking.

## 6.2 Construct Validity

### 6.2.1 Effects of visual task conditions on standing balance (COP excursions)

Studies use COP excursions in AP and ML to assess the standing balance. The increase in the RMS amplitude from fixed surface to sponge surface is due to the increased distortion of the ground reaction forces in an unpredictable manner Desai et al., (2010). This adds up a challenge for maintaining the balance even during stand alone as the sensory input is altered causing a threat to balance. Studies have shown the effect of eliminating or distorting the sensory inputs results in challenging situations for maintaining balance which could lead to loss of balance (Abrahamova et al., 2008;

Davlin et al., 2008; Desai et al., 2010; Singh et al., 2012). When tracking and cognitive game tasks were performed an attempt to restore the balance is made by increasing the COP excursions. Studies performed by Desai et al., (2010) have observed similar findings as that of the present study. The results observed in the present study were also consistent with the findings of Maylor et al., (2001); Kang et al., (2009); Strang et al., (2011). This shows that RMS of the COP excursions can be used for examining standing balance and the tool that we have developed can be used to assess standing balance on different levels of task complexities.

Desai et al., (2010) proposed that the FSA standing mat COP excursion data can also be used to differentiate fallers from non-fallers. When tracking or cognitive game tasks are performed while standing on sponge surface there is a dual-task effect as the participant now has to, not only foveate on the target object appearing on the screen but also has to maintain the balance while rotating the head. This becomes more difficult as there is active as well as passive head movement while maintaining balance. These tasks not only challenge the sensory system because of the distorted ground reaction forces but also the vestibular system because of the head movements. This leads to increase in threat to balance and may also lead to fall.

### 6.2.2 Effects of increase in physical and visual task load on standing balance

A significant increase in the COP excursion during standing on sponge and performing cognitive game task was observed. This indicates that when there is increase in the physical as well as visual task load, maintaining balance becomes difficult resulting in increased COP excursions. When the participants perform visual tasks while standing on sponge surface sensory systems of the body namely visual, vestibular and somatosensory are challenged. The interaction effect indicates that increase in the distortion of ground reaction forces results in increased body sways causing increased COP excursions to maintain balance.

### 6.2.3 Effects of visual task conditions (tracking and cognitive game tasks) on spatial-temporal gait variables and trunk angular velocity

Studies have shown that dual tasking has a significant effect on spatial and temporal gait parameters as compared to normal walking. A review performed by Al Yahya et al., (2011), showed that dual-task significantly increases or decreases the averaged spatial temporal gait parameters of swing time, stride time, double support time, step length, and step width. Nadkarni et al., (2010); Beauchet et al., (2010) also observed decrease in averaged stride time, double support time during dual-task walking.

A study performed by Davie et al., (2012) observed that the simultaneous cognitive tasks have great impact on temporal gait parameters of swing time, step time. Thus the increase in the SST during dual tasking is in contrast with most of the previous studies. The significant change in the above variables may have resulted as the tracking and cognitive game tasks required more foveation and ocular reflexes while performing the tasks.  In day-to-day life this is experienced by the older adults as they walk through the isle of a shopping center when they have to foveate on an item that they need. Thus these tasks when performed while walking can increase the challenge to maintain balance.

Variability is considered to provide an overview on the consistency of locomotor skills and stability during walking Dingwell and Kang et al., (2007). Visual spatial processing of the target location and its relationship with respect to the body and space are the primary aspects of balance and locomotor skills. Many studies have observed these findings Murray et al., (2010); Bagurdes et al., (2008); Nagamatsu et al., (2009). A significant increase in the variability of SST, cycle time and step length was observed when tracking task was performed while walking on treadmill. When cognitive game task was performed there was a significant increase in the variability of SST, swing time, step length and step width. Cycle time was observed to decrease significantly during both visual task performances.

A study performed by Szturm et al., (2013), observed that performing a concurrent cognitive task while walking on treadmill causes divided attention resulting in a significant increase in the COV of the temporal gait parameters (stance time, swing time and double support time). Similarly in the present study COV of the temporal variables was observed to significantly increase during dual tasking (moderate cognitive game task) as compared to normal walking. These findings were consistent with the findings of Al yahya et al., (2011). Studies performed by Van Irsel et al., (2007); Plummer D Amato et al., (2011) examined dual-task effects on swing time variability, step time variability and stance time variability and observed a significant increase during dual tasking as compared to normal walking. These finding was in contrast to the findings of Donoghue et al., (2012) who examined dual-task effects on spatial gait variable of step width and observed a significant increase in step-width variability during dual tasking as compared to normal walk. They used reciting alternate alphabets from A to Z as their cognitive task and used Gait Rite carpet to record gait parameters. The use of Gait Rite allows data to be recorded from 4 to 5 steps and the number of alternate alphabets recited in these 4 to 5 steps will be very less to quantify the cognitive task performances.

In the present study, speed of the treadmill was kept constant during normal and dual-task walking; mainly to avoid the effects of speed on other spatial and temporal gait parameters. This also helps in examining the pure effects of tracking and cognitive game tasks during dual tasking. Studies have shown that speed has a significant effect on the spatial and temporal gait parameters Szturm et al., (2013); Jordan et al., (2007); Kizony et al., (2010). A study performed by Stoquart et al., (2008) also examined the effect of speed on kinematics (stance phase duration and step frequency). They included 12 healthy young adults (mean age 23±2 years) in the study. Participants were asked to walk on treadmill at six predefined speeds (1 to 6 km/hr). They embedded the treadmill with four customized three-dimensional strain-gauge force transducers that recorded the ground reaction forces and computed the step frequency and stance phase durations. They observed a significant increase in the step frequency and significant decrease in stance phase duration as the speed increased. Thus the use of treadmill has more advantages as compared to over ground walking. Speed can be kept as an independent factor to examine pure effects of visual tasks. Data can be recorded from hundreds of steps as the participants walk on the treadmill. Hand rails provide safety to the participants if they experience a threat to balance.

Doi et al., (2011) examined the effects of arithmetic task and colored Stroop test on trunk linear accelerations during walking. They included 34 participants (mean age

71.1 ± 5.1 years) in the study. Participants were asked to perform following task; 1) 20 meters walking at self-selected speed; and 2) walking while performing serial seven subtracting task and 3) walking while performing congruent and incongruent colored Stroop task. Trunk movements were measured using tri axial accelerometers attached on C7 and L3 (MA3-04AC, MicroStone Co., Nagano, Japan). Mean and Coefficient of variation of stride time was computed. Average of the variance calculated by parsing individual steps and peak to peak accelerations of trunk medio-lateral movements were used for the analysis. They computed a new variable called trunk attenuation rate (TAR) using the data collected by upper and lower accelerometers and this was used as measure of trunk control. It is stated that higher the TAR better was the control. They observed that percentage of TAR was significantly greater in medio-lateral and vertical direction but not in antero-posterior during both tasks. The decrease in TAR was greater during subtracting serial seven tasks than Stroop task. To conclude, the study suggests that trunk movements are affected more in medio-lateral direction when the participants are engaged in the concurrent task while walking. In the present study we used the parsing method for analyzing the trunk angular velocity during individual steps while dual tasking.

Van Iersel et al., (2007) observed a significant decrease in gait velocity during verbal fluency task and an increase during attention demanding task. Stride length and stride time variability was decreased during all the concurrent tasks. But there was a significant increase in body sway observed during one of the concurrent task. This might be the result of the change in the gait velocity. To conclude, trunk movements may be related to the gait velocity and thus keeping the gait speed constant by using a treadmill will be helpful in isolating the effect of the same on trunk movements. The findings observed in the present study indicate that when gait speed is kept constant, trunk angular velocity decreases while dual tasking as compared to normal walking.

Hurt et al., (2010) examined the relationship between ML trunk movements (linear and angular) during swing phases and also evaluated the relationship between trunk movements and step width in young and older adults. They included twelve (12) young adults (mean age 24.5 years) and eleven (11) older adults (mean age 60.6 year). Nine (9) passive reflective markers were used to record the body movements by an eight (8) camera motion capture system (Motion Analysis), while the participants walked at a self-selected speed for ten (10) minutes on a motorized treadmill. Markers were placed over L5, S1 vertebrae and bilaterally over the anterior superior iliac spines. Acromion processes and posterior aspect of the calcaneus and second metatarsophalangeal (MTP) joint. They calculated the velocity and accelerations of the trunk center of mass (COM). Step width was calculated as the difference between ML locations of the foot segments during consecutive stance phases. They observed that step-to-step variations of the trunk movements in the ML direction influenced the step width. Trunk COM position and acceleration accounted for 28.1% and 14% variation in step width, respectively. Older adults walked with a smaller step width and less variation in trunk COM movement than younger adults. These two findings were similar to the finding of Moe-Nilssen et al., (2005). In the present study we observed that as the step width variation increased there was decrease in trunk angular velocity. This was observed during dual-task walking. Also, in the present study we have used wireless motion monitors to record trunk angular velocity unlike the expensive camera motion capture system.

An interesting finding of decrease in trunk angular velocity was observed during dual-task walking as compared to normal walking. The individual trajectories of the trunk motion were observed to get clustered during dual-task walking as compared to normal walking. This is a strategy used to stabilize gaze in order to perform visual tasks while walking, Szturm et al., (2013). The head movements during walking result in increased balance demands causing decreased trunk sway. A similar finding was reported by Dingwell et al., (2008). They also observed decrease in trunk motions when participants performed a visual Stroop test while walking on treadmill. Participants were presented with four words, each of different color on the large projector screen placed in front of the treadmill. Participants were asked to verbally respond the color of the word. The study indicates that the reduced trunk motion during the dual-task walking was due to the increased foveation required to identify the colors which indirectly minimized head movements. This is achieved by reducing magnitude of trunk motion. A decrease in the trunk motion during dual-task walking was also observed by Doi et al., (2011). Most of the above studies use expensive motion analysis system or 3d camera marker system to analyze the trunk movement. In the present study we have used wireless miniature sensors that records linear acceleration and angular velocity of the trunk movements and have a range of more than 30 meters.

### 6.2.4 Effects of increased physical load on tracking task performance

A significant decrease in open loop and closed loop COD during walking was observed as compared to standing on fixed and sponge surface. As the physical load was increased, the challenge to maintain the balance while performing the task also increased.

As the participants concentrated on maintaining the balance, tracking task performance was decreased. Performing the tracking tasks was considered to be difficult as foveation on the moving object is more difficult which leads to increased active and passive head movements while standing as well as while walking. Passive linear head movement during walking on treadmill can also decrease tracking task performances. The results observed during standing on fixed and sponge surface in the preset study were consistent with the findings of Schubert et al., (2007); Yu et al., (2010). It is easier to focus on a stationary target but when the target is moving it becomes difficult. When there is increased threat to balance along with the increased visual task complexity, foveation is affected as participants tend to maintain balance first and then foveate on the target.

### 6.2.5 Effects of increased physical load on cognitive game task performances

Cognitive processing needs to be assessed along with balance while dual-tasking. A study performed by Grabiner et al., (2006); Dingwell et al., (2008) used the success rate of Stroop test to assess cognitive performance while walking.  Other several studies have also used simple and single cognitive task of calculations or counting backwards but in the present study we have used a visual task that compels the participants to rotate their head to catch the target which leads to divided attention. Similar to the findings of these studies, in the present study as well we observed decreased success rate when physical load was increased from standing on fixed surface to sponge surface to walking. The reduction in the success rate during walking can be related to the divided attention required to perform the cognitive processing and knowing ones spatial information with respect to the surroundings. The findings of the present study are consistent with the findings of Huffman et al., (2009). In the study performed by Huffman et al, they observed that participants had difficulty in tracking the moving objects on screen while walking. According to Huffman et al., (2009), moving head according to the falling target while recognizing ones location in the space during walking is performed by same source of the sensory system. There was increase in response time and execution time observed in the present study. Passive head movements during walking may result in increased response time and execution time as knowing the location of the falling target and maintaining the position of the paddle becomes difficult while walking.

### 6.3 Standardized Tests

All the participants performed the standardized test for balance (Tandem gait) and based on visual observation the average task performance was graded as fair. All the participants completed the CHAMPS questionnaire and we observed that participants enrolled in this study had higher intensity as well as frequency rates of participation in various physical activities compared to others. Data for one legged stance is been recorded and most of the participants were able to perform the task easily for fifteen seconds. All the above data will be used for the future studies that will compare this age group population with their respective age group populations.

## Chapter 7: Conclusion

In conclusion, the TRP protocol allows us to assess the ability to prioritize the division of attention when visual spatial cognitive tasks are performed while standing and during walking. Also**,** it allows reliable assessment of the effects of compromised attention during the tasks performances. The study reveals that the automated tool measures obtained from the tests of the TRP protocol have moderate to high reliability scores (ICC). The t-values revealed no significant variance in the test retest group means of most of the variables considered in the present study. As ICC scores of moderate to high were observed along with no significant difference in t scores, this indicates that this tool has the ability to record reliable data repeatedly.

The present study also examined the effects that visual task performance had on standing balance performance, stability measures, and gait variables. When the visual tasks were performed there was a significant increase in the COP excursions. A significant interaction effect was observed for COP excursions in ML during cognitive game task performances which indicate that the increase in physical load had a significant effect on the COP excursions by increasing the body sway. The variability of the spatial and temporal gait variables also increased during visual task performance while walking as compared to normal walking. When the physical load was increased visual tracking task and cognitive game task performances significantly decreased.

## Clinical Significance

Community walking can be a complex behavior that involves considerable cognitive processing. During outdoor walking sensory, cognitive and motor processes are required to deal with various environmental challenges, Verghese et al., (2006). An efficient way of assessing balance control in community dwelling adults is required. Cognitive demands of gait control can be examined using dual-task paradigm, where, the interplay of walking and cognitive skills can be measured and analyzed (Abernethy et al., 1988). Fall risk in the older population is increased due to the tasks that require divided attention, especially in people with motor and cognitive impairments (Verghese et al., 2006; Hall et al., 2011). It is important to assess the frail population with fall risks before an incidence of disability or mobility impairment occurs. Evaluation of objective as well as process measures of clinically significant gait variables and cognitive skills is necessary to determine fall risk.  Early detection of gait disorders and fall risk can allow prevention of falls in frail individuals. Hence a good understanding of the effects of dual tasking on gait as well as gaze and cognitive ability is important.

Many researchers are examining the interaction between mobility and cognitive functions using Dual-Task paradigms. In the present study we used a computer game based rehabilitation platform, for assessment and intervention to examine both mobility and cognitive impairments. Moderate to high test re test reliability with low measurement error and significant differences in the two test sessions were observed. A significant effect of dual tasking on the various dependent variables used in the study was also observed. This newly developed tool is inexpensive, easy to operate, portable and can be used in any community centre that has a treadmill. This tool does not require an elaborate laboratory set up of cameras, markers or heavy force plates. It can be used in clinics as it requires only a treadmill and a computer screen to record the required balance and cognitive task data.

## Strengths of the Study

1. Most of the studies that use foot switches during over ground walking or electronic walkway to record gait parameters has some or the other limitations. Studies have proved that use of more than hundred steps is required to assess walking balance during normal as well as dual tasking. But over ground walking allows data recording from few steps only. In the present study, an unobtrusive recording system was used to record the various spatial and temporal gait parameters during normal and dual tasking. This system included instrumentation of the treadmill belt with force sensory array (FSA) mat embedded in thick Teflon. This allowed us to record data from hundreds of steps and at a constant speed. Change in gait speed can affect other spatial temporal gait parameters. (Jordan et al., 2011; Szturm et al., 2013). The use of treadmill allowed us to maintain the speed constant thus we were able to record and assess pure effects of cognitive concurrent task.
2. The use of tracking and cognitive tasks allowed us to not only evaluates the objective measures such as Success Rate but also the process measures such as Averaged response time, and Averaged Movement execution time. Most of the studies that examine the effects of dual tasking do not evaluate the cognitive task appropriately or do not consider analysing the cognitive task performances. Even

if it is done, then only objective measures such as success rate or total time are recorded. But it is important to examine the process measures also along with the balance measures. In the present study we not only examined the objective and process measures of the visual spatial cognitive tasks but also the balance/ stability measures simultaneously. Thus, this tool can be used to assess both aspects of human behavior (cognitive, balance and locomotor skills) at the same time. Also, an interaction effect can be examined when both the physical and visual spatial cognitive task load is increased.

3. The results obtained for the reliability were moderate to high along with no significant differences in the averages of the two test sessions. This shows that the major factors affecting reliability scores such as systemic bias or measurement error were reduced as the calibration of the instruments were kept constant and the order at which the tasks were performed was randomized. Thus by taking these precautions the newly developed tool produces reliable measures to assess cognitive and balance impairments together.

## Limitations and Future Implications

1. The results of the present study are difficult to be generalized as the data was collected on healthy older adults who are physically fit and those who do exercises on daily basis. A treatment study will be beneficial on frail older adults who have a history of fall to ensure the outcomes of the tool developed.
2. Even though we observed most of the spatial and temporal gait parameters it would have been better if we would have been able to analyze the variations or

the discrepancies in between the two legs (right and left). Future studies should be designed to concentrate on evaluating the variations in between the two legs in more depth.

3. The use of treadmill along with the virtual reality tools can form the basis of quantifying balance and mobility task performances along with the standardized grading of the cognitive task performances.
4. Frequency analysis in the future studies can be helpful in analysing the dual-task effects in broader and précised manner.
5. Future studies can be performed on young and older adults to see the effects of age on the gait and cognitive performances during dual tasking.
6. Use of Sample Entropy Analysis on the data recorded from the tool can help in making the analysis faster and novel in its approach. We hope that this approach can also be used to differentiate fallers from non-fallers in future studies.
7. To examine the strength of each variable assumed to determine the nature of human behavior (cognitive or balance), Principle Component Analysis can be performed in later studies.

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