# Use of a dual task paradigm to examine the effects of age on mobility and cognitive performances

by

Anuprita Kanitkar

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**Abstract**

The increase in the aging population has become one of the most important problems of our society in last few decades. As people grow older, they are at risk of falling and consequent injuries due to the effects of aging. A fall may be the first indication of an undetected illness related to the effects of aging. This study demonstrates the effects of aging on balance, spatio-temporal gait parameters, gaze stability, and cognitive skills under single task conditions and during dual-tasks conditions. In the present study, we included following three groups: Group 1: 30 young healthy adults (aged 20 ± 3 years); Group 2: 30 adults (aged 61.4 ± 4.4 years); Group 3: 30 older adults (aged 75 ± 4.5 years). A computer game based rehabilitation platform has been developed and was used for the single and dual task performance in standing and during treadmill walking. We observed that there was a significant age effect while dual tasking on standing balance, spatial and temporal gait parameters, gaze performance, and cognitive task performance. To conclude, this study shows a vast decline in walking and standing balance and ability to divide attention during dual tasking between the age groups 55-70 years and 71- 85 years and compares both these age groups with the more normative, healthy, young and athletic, 20-30 years old population.

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## Dedication

I would like to dedicate my thesis to my adored husband, Vedant Sakhalkar without whom I would not be here today, whose endless support and admiration always motivated me; also to my parents as well as Aneesh and Aditi Kanitkar for being my strength and inspiration. I would also like to show my gratitude to my family for their constant support and encouragement.

**Anuprita Kanitkar**

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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

TMT: Trail Making Test

TUG: Timed Up and Go

UFOV: Useful Field of View test

# Chapter 1: Introduction

Walking is considered a complex task and many studies have observed a close link between mobility, cognitive ability and aging. Thus, as age increases, cognitive ability decreases, which in turn decreases mobility skills. The increase in the aging population has become one of the most important problems of our society in last few decades. According to the National Fall Prevention Workshop conducted by Center for Health Promotion (British Columbia), about one in three Canadian older adults experience falls once a year. These falls are found to be the leading cause of injury related hospitalization of older adults.

The decline in executive cognitive function with age, combined with mobility limitations, can result in increased risk of falling, Gleason et al., (2009). A number of studies have examined the interaction between aging and various mobility and cognitive skills with the help of a dual task paradigm, Bock et al., (2011); Yogev et al., (2012). The dual task (DT) paradigm is a procedure that requires an individual to perform two simultaneous tasks, such as walking while performing a cognitive task. As people grow older, they are at risk of falls and consequent injuries due to the effects of aging. Aging in humans is a multidimensional process of physical, psychological, and social change. A fall may be the first indication of an undetected illness related to the effects of aging. We used dual task paradigm to assess the effect of aging on gaze stability, mobility and cognitive skills using a computer game based rehabilitation platform. In the present study we used an inexpensive pressure mapping system to instrument a treadmill and record foot contact forces during walking rather than using an expensive force platform, or 3-D camera system. This study demonstrates the effects of aging on balance, spatio-temporal gait parameters, gaze stability, and cognitive skills under single task conditions and during dual-tasks conditions.

# Chapter 2: Literature Review

## 2.1 Balance and Aging

Balance while standing involves maintaining the line of gravity of a body within the base of support with minimal postural sway. Multiple sensory systems including the vestibular, somato-sensory, and visual systems coordinate to maintain balance. Changes in body position with respect to the base of support have to be sensed and analyzed by the brain regardless of whether the body moves or the base. Physiotherapists often introduce balance training into treatment plans for the elderly population.

The Sensory Organization Test (SOT), protocol developed by Nashner (1971) measures the contribution of different sources of spatial information provided by each sensor. This test was further commercialized and called "Equi-test" (Petrek and Black et al., 1990). The SOT contains six sensory balance tests with which COP movements are recorded. The magnitude of COP excursion indicates 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 the participants receive appropriate information from vestibular, somato-sensory and visual sensors.
2. Standing with eyes closed on a fixed surface: The visual signals are eliminated in this condition.
3. Standing on fixed surface with visual surround that sways proportionately to body sway: the body sway and the visual surround move synchronously. Thus there is no motion of head relative to the visual surround. This is referred to as the 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: the body sway and the visual surround move synchronously. This effectively cancels out the motor and somato-sensory signals of ankle motion.

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

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

Nashner et al., (1981) used the SOT to examine 12 participants with vestibular dysfunction and noticed that, in conditions 1 to 3, 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 resulted in greater weighting of vestibular and visual inputs. In condition 5, sway was observed to be substantially increased. And 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. Healthy young adults and participants with vestibular deficits maintained their balance with increased sway. This study demonstrated how sensory inputs can be manipulated by eliminating or distorting one sense at a time resulting in greater dependence on other senses. As long as reliable inputs regarding earth vertical or earth horizontal were available, balance was well maintained. However, as the balance tasks became harder and visual and somato-sensory distortions were advanced, there was a greater loss of balance and falls. Furthermore, participants with greater vestibular loss had more difficulty in regulating 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 when more than one is absent or is unreliable, balance is hard to achieve and maintain, 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), who were independent in ambulation and had no neurological deficits to 34 young healthy adults (mean age 35 years). A significant age effect was observed for condition 4 (eyes open, sway stabilized) and condition 5 and 6 (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% lost their balance on condition 6. In comparison, only 6% of younger adults lost balance during condition 5 and 9% on condition 6. To conclude, the author states 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 is the support surface condition important, but visual information also plays a crucial role.

Shumway- Cook and Horak et al., (1986) developed a simpler and less expensive version of the SOT called the Clinical Test of Sensory Interaction and Balance (CTSIB). Instead of using a sway referenced platform, they used a sponge to distort the signals coming from the ground. Foam is beneficial over the SOT because the sway referencing of surface is not limited to the pitch plane but it can sway in almost all directions. The compliant sponge surface alters the ground reaction forces under the feet (Blackburn 2003, Patel, Fransson, Lush, 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 the patient to maintain balance to a maximum of 30 seconds. The CTSIB is inexpensive and simpler to reproduce within clinical settings. 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., Kuo et al., (1998); Blackburn et al., (2003), Creath et al., (2005).

Lord et al., (1994) assessed postural sway in twenty five participants (10 men and 15 women with mean age 67.1 ± 7.6 years). Participants were grouped into two groups: 1) diabetics with no neurological deficits and 2) control participants with no diagnosis of diabetes or neurological deficits. All the participants were asked to perform two tasks with eyes open and eyes closed on a firm and a compliant sponge surface. The total sway was measured for 30 seconds using the sway meter. They observed that the performance of the participants with diabetes was worse than the other group 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 ($p=0.01$).

Desai et al., (2005) performed a study to assess the use of a Dynamic Balance Assessment test to differentiate fallers from non-fallers. They included 72 community dwelling individuals (aged 65 years and older) in the study. Participants performed 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 sensitive mat and peak to peak excursions, and total sway path length in AP and ML directions were used to analyze the performance. A significant increase in the COP excursions on the compliant surface during eyes closed, during trunk rotations and flexion extension movements that were observed COP displacements during performance on the sponge surface and not the normal fixed surface were able to predict falls. The analysis method used to examine the COP displacements during different tasks and under different surface conditions is an appropriate method to examine dynamic balance control. The study concludes that the scores computed from the 6 tasks were able to identify the fallers from non-fallers.

Abrahamova et al., (2008) examined the changes in COP parameters of quiet stance under four conditions due to the effect of aging. Eighty-one healthy participants were recruited and 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 CTSIB tests 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 direction as their dependant variables. Root Mean Square (RMS) and total area of COP displacement was also computed. They looked for changes in COP displacement related to age and in condition with alteration of sensory information. The findings were similar to that of the SOT where conditions 5 and 6 showed considerable increase in sway and loss of balance (LOB) was often seen.

Strang et al., (2011) examined postural sway while standing on firm and compliant surfaces using COP displacement variables of path length, area of displacement, sample entropy and normalized path length during two conditions of eyes open and eyes closed. 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 balance disorders and no history of lower extremity injury within past six months. For the balance training program participants were asked to perform a set of nine high level balance training exercises. Participants performed the 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. COP movements in AP and ML directions during the eyes open and closed conditions on firm and compliant surfaces were recorded using a force plate. They observed the following results: there was a significant increase in the area of COP movement and path length on the compliant surface compared with the fixed surface (p= 0.001); significant increase in COP movements during eyes closed condition than eyes open.

### 2.2 Summary

Balance control is a complex multi-dimensional process and it is a part of human behavior. Assessment of this behavior in community dwelling older populations requires appropriate and accurate tools and measures. Assessment tools available, such as the SOT instruments or force plates are expensive and not readily available in community settings. The CTSIB on the other hand is an easy to use tool but the only factor it considers is the Time variable. The use of body sway as an outcome measure is a reliable method of balance assessment but the sensors must be attached onto the body segment. Many recent studies have used a compliant sponge surface to distort the sensory input signals instead of the sway referencing conditions of the SOT. Some studies have used force plates to record COP excursion to index stability. In these studies the compliant surface is placed on top of the force plate. It is possible that the use of the sponge over the force plate may not be the most appropriate, since the distortion of the ground reaction forces occurs before the force plate detects the vertical force signals.

The use of a pressure sensory mat over the sponge is helpful as it detects the actual COP excursion when the ground reaction forces are distorted. To conclude, the use of a sponge surface to distort the ground reaction forces along with the force sensory mat over the sponge is helpful in evaluating sensory and the motor processes while maintaining standing balance.

### 2.3 Age related Balance, Mobility and Cognitive Limitations

Maintaining stability during walking and performing activities of daily living is a multi-dimensional process and can be very complex. Walking requires a high level of motor and cognitive control, to address threats to balance while attending to outdoor environment and subsequent cognitive tasks. The following studies show the links between balance control during mobility and cognition.

Verghese et al (2006) conducted a study to measure the prevalence and incidence of gait disorders based on clinical evaluation, time to institutionalization and death. They included 488 participants (age 70-90 years) in the study. Participants were asked to walk up and down a well-lit hallway at their normal speed and their walking pattern was observed. On the basis of visual inspection gait patterns were divided into abnormal and normal. Abnormal gait patterns were then divided into neurological and non-neurological. The neurological gait abnormalities were categorized as unsteady if the participant swayed more or lost balance under two or more of the following conditions; 1) tandem walking; 2) walking while making turns. The abnormalities were graded as mild, moderate or severe. Cognitive functions were assessed using a neurological test. They observed that; 35% of the participants showed abnormal gait and 15.7% had a neurological gait. They concluded that people with abnormal gait showed greater risk of institutionalization and death.

In a further study, Verghese et al., (2009) evaluated the association of variability of stride length, cadence, swing time, gait speed and double support time with the incidence of fall rate. They included 597 participants (mean age= 80.5) years in their study. Participants were asked to walk on the GAITRite carpet and spatio temporal gait parameters were calculated using 5 steps. Risk ratios were used to analyze the data after factor analysis which divided the data into three factors; Pace factor, Rhythm factor and variability factor. They observed the following results: decrease in gait speed was strongly associated with the increased risk of falling (RR=1.078). Stride length variability (RR= 1.128) and swing time variability (RR= 1.011), were highly associated with increased risk of falling. This is in consistent with Housdorff et al (2001)

Gleason et al., (2009) examined the association of rate of falls with cognitive impairment. They included 172 participants (aged 65 years and older) in the study. They examined the cognitive status by using Mini Mental Status Examination (MMSE) (Folstein et al 1975). All the participants were followed up with for a period of one year with the help of monthly calendars. Falls were recorded based on self-report in the monthly calendars and the participants were contacted by telephone for details of that fall. After a complete follow up for one year, the rate ratio of the falls was calculated and it was observed that participants who scored in between 22 to 30 on the MMSE scale had a moderate fall rate ratio of 1.25.

A study conducted by Shin et al., (2009) evaluated the association of cognitive status and level of activities of daily living (ADL) with risk of falling. They included 335 Korean community dwelling older adults (mean age 72.87 years). The Korean version of the MMSE, Folstein et al., (1975) was used for the assessment of cognitive status. They observed the following results; 15 % of the participants experienced a fall in the follow up period of one year. This was experienced due to the following reasons; slipping (52.1%), loss of balance (8.3%), tripped (6.3%) and while walking (6.3%). Participants experienced 52 % of falls during indoor walking, where as 41.7% of falls occurred during outdoor walking. Fallers had lower exercise behavior and participated less in activities of daily living. Older adults who scored one unit greater on ADL scale were 1.02 times more likely to be non-fallers. Thus, as the level of participation in activities of daily living increases the risk of falling decreases.

A study performed by Hong et al., (2010), evaluated the incidence of fall based on increasing age, cognitive impairment or depression, visual deficit and decreased daily activities. They included 10,254 participants and divided them in two groups depending on their age. One group was younger adults (aged 45 to 64 years) and other was older adults (aged 65 to 85 years). Cognitive status was assessed using the Korean version of MMSE, Kang et al., (1997) and participants scoring 23 or less were considered cognitively impaired. They observed that the older adult group had a higher rate of falls (6.3%) compared with the younger adult group (4.1%) and as the age increased the rate of falls also increased, i.e. the rate for participants aged 75 to 79 years was 8.0%. The study also examined the rate of falls requiring treatment which was observed to be 4.3% more in the older adults than the younger adult group. This was also observed to be increased with age, i.e. participants who were 85 years of age had the highest rate of (6.0%) falls requiring treatment.

A study performed by Chen et al., (2012) examined the association of processing speed and response inhibition with falls in a sample of 509 participants (community dwelling aged 63 to 90 years) over a period of 3 years. Baseline assessment of the demographic information was done and the cognitive status was assessed using the MMSE, Folstein et al., (1975). Balance was assessed using the Turn 360 test and number of steps was counted. Health status was assessed using a self-report history of chronic conditions such as diabetes, heart diseases and medications. Processing speed, set shifting, response inhibition and psychomotor speed were assessed using the Useful Field of View (UFOV) test, Pattern Comparison test, Trail Making test (Part A and B), Stroop test and DSS test respectively. They calculated the Odds Ratio and observed how well these variables could predict falls. They observed balance impairment (OR: 1.55; p= 0.001) and psychomotor speed (OR: 6.19; p = 0.01) variables to be moderately associated with recurrent falls after a follow up period of 6 years. Previous studies have also shown that executive functions can predict falls, Holzter et al., (2007); Springer et al., (2006). Processing speed was also found to be a predictor of fall, Joy et al., (2003)

McGough et al., (2011) performed a study to examine the association between change in gait speed and performance on the TMT- B and Stroop test. They also examined the association between the Timed up and Go test (TUG) and the two executive function tests. Over 201 sedentary older adults with cognitive impairments took part in the study. Participants walked on an 8 foot hallway and the time taken to finish was used to calculate gait speed. Time taken to finish the TUG was recorded and analyzed. They observed a moderate 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 the Trail making Test ($r^2$ = 0.8) and moderately associated with the Stroop test (r2 = 0.6).

Bruce-Keller et al., (2011) examined the association between a cognitive task and change in gait parameters such as gait speed, cadence and stride length. The control group had 50 non demented participants and the study group had 50 demented participants. To assess the physical function the participants were asked to perform three trials of independent walking with a verbal fluency task of spelling one unique five letter word backwards. They walked on a walkway of 11 meters (11-12 steps). The Gait rite system provided 7 meters walkway with 2 meters distance on each side for acceleration and deceleration. The correlation coefficients show lower but significant associations between the means and standard deviations of processing speed of the digital symbol test and dual task gait parameters, namely cadence(r= 0.52) and stride length (r=0.54) and a moderate association with gait velocity (r=0.71) in the combined data of demented plus non demented group. The verbal fluency test results were mildly associated with single as well as dual task walking variables. Namely, single task stride length (r= 0.50) dual task stride length (r= 0.54), single task gait velocity (r= 0.54) and dual task gait velocity (r= 0.66). The results of the clock drawing test were weakly associated with the single task gait variables, namely, stride length (r=0.46) and gait velocity (r=0.47) and the dual task variables namely cadence (r=0.45) stride length (r= 0.52) gait speed (r= 0.62).

A study performed by Ijmker et al., (2012), examined the association between change in gait speed and the coefficient of variation (COV) of stride time and performance of executive task functions during dual tasking. They included participants with dementia (aged 75 to 87 years), 12 young participants (aged 55 to 70 years) and 14 participants (aged 75 to 85 years) in the study. Participants were asked to walk alone, up and down a 10 m walkway while performing a dual task. The dual task was walking while performing a consecutive task of letter fluency. During dual tasking participants were asked to perform a consecutive task of letter fluency. Gait parameters were derived from data parsed using heel strikes and the peak from the AP trunk accelerations. It was observed that, COV of stride time was significantly increased and gait speed significantly decreased for participants with cognitive impairment. Mild correlation was also obtained between executive task performance and gait variables (r> 0.51).

## 2.4 Effects of Aging on Dual Task Ability

Various studies demonstrate the influence of performing concurrent cognitive tasks on gait variables during walking. To perform most daily life activities, indoor or outdoor, the ability to dual task is required in order to control balance during mobility while concurrently performing cognitive, executive or memory function tasks. The following are studies that show such effects. The following are studies that show such effects.

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 and ML and AP angular velocities of the trunk. They included 59 participants (mean age 73.5 years) who were 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's from 100's and 13's from 100's, and citing words starting with the letters K and L. They used a Gait rite carpet to record gait velocity. Two angular velocity transducers (Sway star) were attached on the trunk and lumbar region with the use of a belt to record angular velocity in the medio lateral and antero posterior direction. They observed a significant increase in the RMS of body sway during dual task conditions. (p= 0.01). A significantly decreased gait velocity was observed during dual task conditions. (p= 0.01). Stride length and stride time variability significantly increased during dual task conditions. (p= 0.01). Concurrent task performances such as calculations and citing words were not significantly changed during dual task conditions as compared to the single task condition.

Theill et al., (2011) examined the effects of single and dual task walking on gait speed in 711 participants (mean age 77.2± 6.2 years). The concurrent tasks consisted of the following: counting backwards from 50 dividing it by 2 and enumerating animal's names. The participants were divided into two groups based on MMSE scores more or less than 16 1) cognitively healthy and 2) cognitively Average. Average gait velocity was calculated using approximately 4 to 5 steps on a Gait Rite carpet. The number of correct calculations from the first task and the number of correct responses for enumerating animal names were recorded. A repeated measures ANOVA showed that the preferred speed of the cognitively impaired participant group was significantly lower (p=0.01) than the cognitively healthy participant group. The cognitively impaired group had lower baseline gait velocity and a greater loss in gait velocity but not in cognitive performance during dual tasks than cognitively healthy group (p= 0.01), however cognitive performance during dual tasks was not different between the groups.

A study conducted by Muir et al., (2011), examined the effects of dual tasking on gait speed and stride time variability. They also evaluated; 1) gait variables under single and dual task conditions in older adults with Mild Cognitive Impairment (MCI), Alzheimer's Disease (AD) and normal cognition, who did not have a previous history of falls; 2) how the gait parameters change with the change within the type of concurrent task and 3) gait velocity and stride time variability to define fall risk. They included 22 participants with normal cognition (aged 71+/- 5 years), 29 with mild cognitive impairment (aged 73.6+/-6.2 years), and 23 with Alzheimer's disease (aged 77.5+/-5 years) in the study. The Gait rite system was used to quantify gait parameters from 4 to 5 steps. The average gait velocity, stride time and coefficient of variation of stride time variability were used for analysis. They observed that participants with normal cognition had significantly less variation in the gait parameters as compared to the other two groups. The participants in the Alzheimer's group performed worst in the concurrent task where their gait speed was significantly decreased as compared to other two groups (p=0.0002). The stride time variability was also observed to be significantly increased in the Alzheimer's group participants. The participants in the normal cognition group performed significantly better than the other two groups.

Lamoth et al., (2011) examined 13 participants with dementia (mean age 82.6 years) and13 without dementia (mean age 79.4 years) to study the effect of dual task conditions on variations in stride time and gait velocity under normal walking conditions and walking while performing letter fluency tasks (i.e. naming as many words as they could, starting with a pre defined letter R or G). Participants walked for 3 minutes in a well lit 40 m long corridor at self-selected speed. AP acceleration signals were used to index the time of left and right foot contacts. Stride times were calculated from the foot contacts, by subtracting subsequent foot contact times of the same foot. One hundred fifty 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. A significant decrease in gait speed (p= 0.01) was observed during dual task conditions in participants with dementia as compared to the participants without dementia. Also the stride time variability was significantly increased (p= 01) 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 in contrast to the results in a study done by Muir et al 2011.

## 2.5 Summary

The most common and consistent finding of dual-task studies that compare walking alone to walking plus performing concurrent tasks has been the reduction of gait speed. A number of studies do not consider the concurrent task effects on the spatial temporal gait variables such as double support time, step width, and stance time in the analysis. This is mainly because the gait speed for each participant varies, which makes it difficult to compare. Numerous DT studies have also observed that the preferred walking speed for elderly adults is slower than for young adults; again the effect of age on speed and the effect of speed on other gait parameters is not considered.

Many studies have quantified gait variables using data collected from 4 to 5 steps using the Gait Rite carpet. Hundreds of steps are required for quantifying stability during walking, Hollman et al., (2010). Further, studies show that gait speed is an important factor that affects most kinetic and kinematic gait variables, Jordan et al., (2006); Kizony et al., (2010). These factors have received little consideration in most published research.

The concurrent cognitive tasks used in most of the studies are not graded explicitly. They are usually graded on the basis of the number of responses made or the amount of reaction time but they do not evaluate the accuracy or the process measures of the task. This method of analysis has potential to lead to misinterpretation of the data, thus affecting the results.

## Statement of Problem

A decline in performance of mobility and cognitive skills has become a hindrance in the successful aging of our society and the ability to participate in community life. The decline in mobility skills may be the result of the contribution of a number of factors. Future adverse health events can be diagnosed early by considering the decline in balance and mobility skills as an early indicator. Many studies have used balance performance and gait outcome measures to assess the health status, quality of life, and physical function in older adults. Community walking is not a simple task but rather, it is a composite of different complex processes requiring visual spatial attention, gaze stability and higher level motor control to address threats to balance. The dual task paradigm is a process that requires performing two simultaneous tasks, to grade individual performances and observe the interaction between the two tasks.

Most studies use over ground walking to evaluate the interaction between concurrent cognitive tasks and gait. Typically spatio-temporal gait variables are obtained using the Gait Rite system or multiple camera motion analysis systems. Limitations of these systems include the length of the Gait Rite carpet which is only 5-6 meters (i.e. 4 to 5 seconds), and the capture volume of video motion analysis system which is only a few steps. The vast majority of studies show that participants reduce their walking speed during the DT condition. This is more likely a précise planned strategy to avoid any other threat to balance or to allow more processing time for the cognitive task. A decrease in walking speed can also produce changes in most spatial temporal or kinematic gait measures that are dependent on gait speed and this also has not been considered during many analyses. Variability of gait parameters such as stride length, step width, single and double support time increase as age increases. Numerous studies have examined the effects of aging and various mobility and cognitive skills with the help of a dual task paradigm, however, various other aspects such as gaze stability or visual-spatial task performances have not been considered. The purpose of the present study was to examine the effects of aging on balance, gaze stability, walking function balance and cognitive skills during single task and dual-tasks conditions.

A computer game based rehabilitation platform has been developed and was used for the single and dual task performance in standing and during treadmill walking. A treadmill instrumented with a pressure mapping system was used for quantification of spatial temporal gait parameters. Gait speed which affects other spatial and temporal gait parameters was kept constant to examine the pure effects of performing concurrent tasks on balance (standing and walking). The treadmill allowed the speed to be kept constant thus permitting the other spatial temporal gait parameters to remain unaffected. The use of a treadmill also allowed data from over 50 consecutive steps to be collected for analysis. The cognitive task that was used included components of visual-spatial task performance that assessed not only the number of errors but also the quality of random head movements. From the visual spatial memory task, success rate of catching the target, accuracy of the movement execution and response time (which were the process measures) could be obtained.  Thus the computer based assessment tool automated measures allowed grading of different performance levels of the participants and comparison of the difference between the performance of participants of different age groups (old and oldest).

**Objectives**

1. To examine the effects of age (three groups) on performance measures of balance, gaze and spatial and temporal gait variables during single task condition.
2. To examine the effects of aging on DT performance during standing balance activities. (DT included performing a cognitive task).
3. To examine the effects of aging on DT performance and spatio-temporal gait parameters. (DT included performing head tracking task and cognitive task).

**Hypothesis**

For the single task conditions the following were hypothesized

1. There will be no effect of age on standing balance with eyes open on sponge (single task condition)
2. There will be no effect of age on gaze performance when standing on a fixed surface (single task condition)
3. There will be no effect of age on cognitive game performance when standing on fixed surface (single task condition)
4. There will be a significant age effect on step length/width step time and single support time during treadmill walking alone.

For dual-task conditions the following were hypothesized:

1. Age will have a significant effect on dual-task balance performance when standing on the sponge surface. This will be the case for both head tracking and cognitive game tasks.
2. Age will have a significant effect on dual-task gait performance. This will be the case for both head tracking and cognitive game tasks.
3. Age will have a significant effect on gaze performance during treadmill walking.
4. Age will have a significant effect on cognitive performance during treadmill walking.

# Chapter 3: Methods

## 3.1 Participants

In the present study we included following three different groups:

Group 1: 30 young healthy adults (aged 20 ± 3 years) named the "young group", (Sabapathy S., 2014)

Group 2: 30 adults (aged 61.4 ± 4.4 years) named the "older group" (Sakhalkar V., 2013)

Group 3: 30 old adults (aged 75years ± 4.5 years) named the "oldest group"

**Inclusion Criteria**

All participants were active members of the Reh-Fit centre and attended exercise classes at least once per week. All participants were able to clearly see the visual targets on the computer monitor at a viewing distance of 1 meter.

**Exclusion Criteria**

Participants were excluded if they had cardio-vascular disease determined by standard testing conducted at the Reh-Fit centre.

All participants were screened and excluded if they reported a diagnosis of the following conditions: (a) muscular-skeletal injuries or disease (e.g. rheumatoid arthritis, advanced hip/knee osteoporosis or arthroplasty (b) neurological disorders (e.g. Stroke, multiple sclerosis, ALS, brain tumor, Parkinson's disease, Vestibular disorders, (c) any recent medical illness that would affects their balance or ability to walk for a period of at least 6 minutes.

**3.2 Instruments**

**Standing FSA mat**

The FSA Pressure Sensor Array mat (Vista Medicals Ltd, Winnipeg, Canada) was used to record the centre of foot pressure (COP) as the participants performed various visual tasks for standing balance on both a fixed surface and compliant surface:

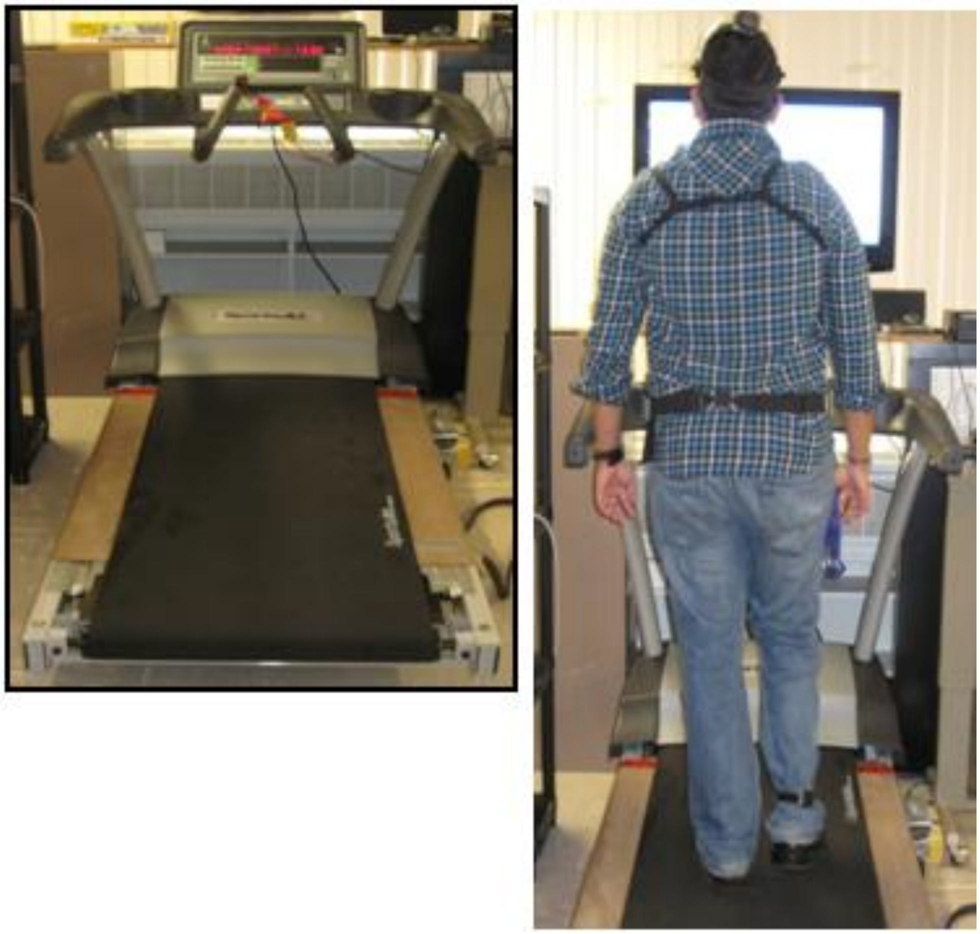
Picture 1 below illustrates the Force Sensory Array (FSA) mat which has 256 sensors (16 by 16) and each sensor covers area of 2.8 $cm^2$.

**Picture 1: FSA Pressure Sensor Array mat (Vista Medicals Ltd, Winnipeg, Canada)**

**Treadmill instrumented with force sensory mat**

Picture 2 shows the treadmill (Sports Art Fitness Ltd) with hand rails and an overhead harness to provide safety while performing the tasks, which was used to keep the walking speed constant at a speed of 0.9meters/second. A Force Sensor Array (FSA) mat (Vista Medicals Ltd, Winnipeg, Canada) wrapped in thick Teflon was attached underneath the treadmill belt for recording the spatial temporal gait parameters. The treadmill FSA Pressure Array mat has the same size but twice as many sensors (512 sensors; 16 by 32) embedded in thick Teflon. This arrangement is somewhat similar to Gait Rite carpet, however since it is underneath the treadmill belt; it is possible to record hundreds of steps during normal as well as dual task walking. The custom FSA treadmill pressure mat was used to record foot contact forces during treadmill walking and COP was computed and used to quantify the spatial-temporal gait variables.

**Picture 2: Treadmill instrumented with force sensory mat**



**Gyration Air mouse**

Picture 3 represents a thoroughly tested and inexpensive commercial Gyration Air Mouse placed on a helmet allowing the participants to interact with the on screen cursor through head rotation and keeping the hands free, (Szturm et al., 2013; Shih et al., 2010; 2011). This motion mouse translates head rotation (left-right /or up-down) into on screen cursor motion identical to a standard computer mouse and allows participants to interact with the screen.

**Picture 3: Gyration Air mouse mounted on a helmet**

**Motion Monitors**

The inertial monitors are cube like sensors, which are wireless and have a range of 30 m for recording the data. Each monitor is comprised of an accelerometer, a gyroscope and a magnetometer which collects data in all three directions (Antero posterior, Medio lateral and Vertical). Three motion monitors were attached to the participants (one on the trunk, one on the pelvis and one on the foot). During heel strike an artifact that is vertical acceleration data appears. This was used to parse the walking data for trunk angular velocity with each individual step. The average of the variance was calculated from each step and was used to analyze stability during normal walking and walking while performing dual tasks.

## 3.3 Study Protocol

The testing protocol was explained to the participants in the first visit along with the complete consent form which was then signed before they started with any of the tests in the protocol. The following functional tests were performed by the participants before they started the head tracking and cognitive game tasks: 1) Standing on both fixed and compliant surface with eyes open and eyes closed for 45 seconds; as per Clinical Test of Sensory Interaction and Balance (CTSIB); 2) Tandem gait for 10 meters. This was performed on the treadmill as it had safety hand rails which provided easy and quick support. The Treadmill Rehabilitation Platform (TRP) test protocol was then performed while standing on a fixed surface; then on a compliant sponge with a wooden board on it; and finally while walking on treadmill at a speed of 0.9 m/s.

**Head tracking Task** (with respect to head rotation): There were two cursors of different colors and shapes appearing on the screen. One was moving sinusoidal, left to right in a rhythmic motion (target cursor). The motion of the second cursor was bound to the head rotation via the head tracking air mouse. The required task was to overlap the two cursors during the motion of the cursor from left to right for 45 seconds. This task required continuous foveation to determine the amount of overlap (error) between the target cursor and the head cursor.

**Cognitive Game Task**: A custom made computer game that assessed targeted executive functions such as visual spatial processing, cognitive interference and processing speed was used. In this classic paddle-based game the participants had to move the game paddle in order to catch the vertically falling targets. The movement of the game paddle was synchronized to the head rotation through the air mouse. The target object (which was a brightly colored circle) appeared every two seconds at random locations on the monitor from the centre to the top edge. Thus participants were presented with a target object that appeared on the screen at the top and moved vertically downwards. The participants were asked to move the game paddle by rotating their head to catch the target object. In addition to the target object another different object (distracter) appeared and fell vertically. When participants hit the distracter they would get a penalty of three seconds as the game sprite was destroyed. Hence the participants were informed to foveate on the target, make a decision and then hit the target.

### 3.4 Test Protocol

Participants were given a demonstration of the entire testing protocol prior to the start of data recording. Once they understood the tests, an informed consent was obtained and they were fitted with the head band and three miniature motion monitors using straps (one around the sternum, one around waist and one around ankle). Participants were asked to perform following tests in different physical conditions:

1. Standing on fixed and sponge surface:
    a. Eyes open
    b. Eyes Closed

c. Head tracking Task

d. Cognitive Game Task

2. Walking on treadmill:

a. Normal Walking at a speed of 0.9 m/s

b. Walking while performing the head tracking and cognitive game task

The Community Healthy Activities Model Program for Seniors (CHAMPS) which is a physical activity questionnaire that covers various aspects of the concept of participation in daily living was used to assess the duration and intensity of daily activities such as walking, gardening, housework, sports activities, and volunteering, (Stewart et al., 2001). The CHAMPS questionnaire was given to the participants to take home after the first session and they were asked to complete it at their convenience and return it at the time of second session. This would have taken about 20 minutes. The neuropsychological test used in the study was the trail making test. Time to complete the test was recorded.

**3.5 Data Collection and Analysis**

**Dynamic standing balance measures:**

Antero posterior (AP) and Medio-lateral (ML) COP excursions were recorded using the Force Sensory Array (FSA) pressure mapping mat. Root mean Square (RMS) of the COP excursions in AP and ML directions were derived and used to assess balance, (Desai et al., 2010, Szturm et al., 2013). Figure 1 is divided into three different panels: Panel A represents the treadmill set up with a participant performing tasks from the protocol. Panel B represents the COP excursions recorded on the treadmill mat to quantify various gait variables. Panel C represents the individual COP excursion in the AP and ML direction which was used to extract spatial and temporal gait variables. Figure 2 below represents the individual COP excursions recorded when participants performed single and dual tasks while standing on fixed and sponge surface.

**Figure 1: Panel A represents the treadmill set up with a participant performing tasks from the protocol. Panel B represents the COP excursions recorded on the treadmill mat to quantify various gait variables. Panel C represents the individual COP excursion in the AP and ML direction which was used to extract spatial and temporal gait variables.**

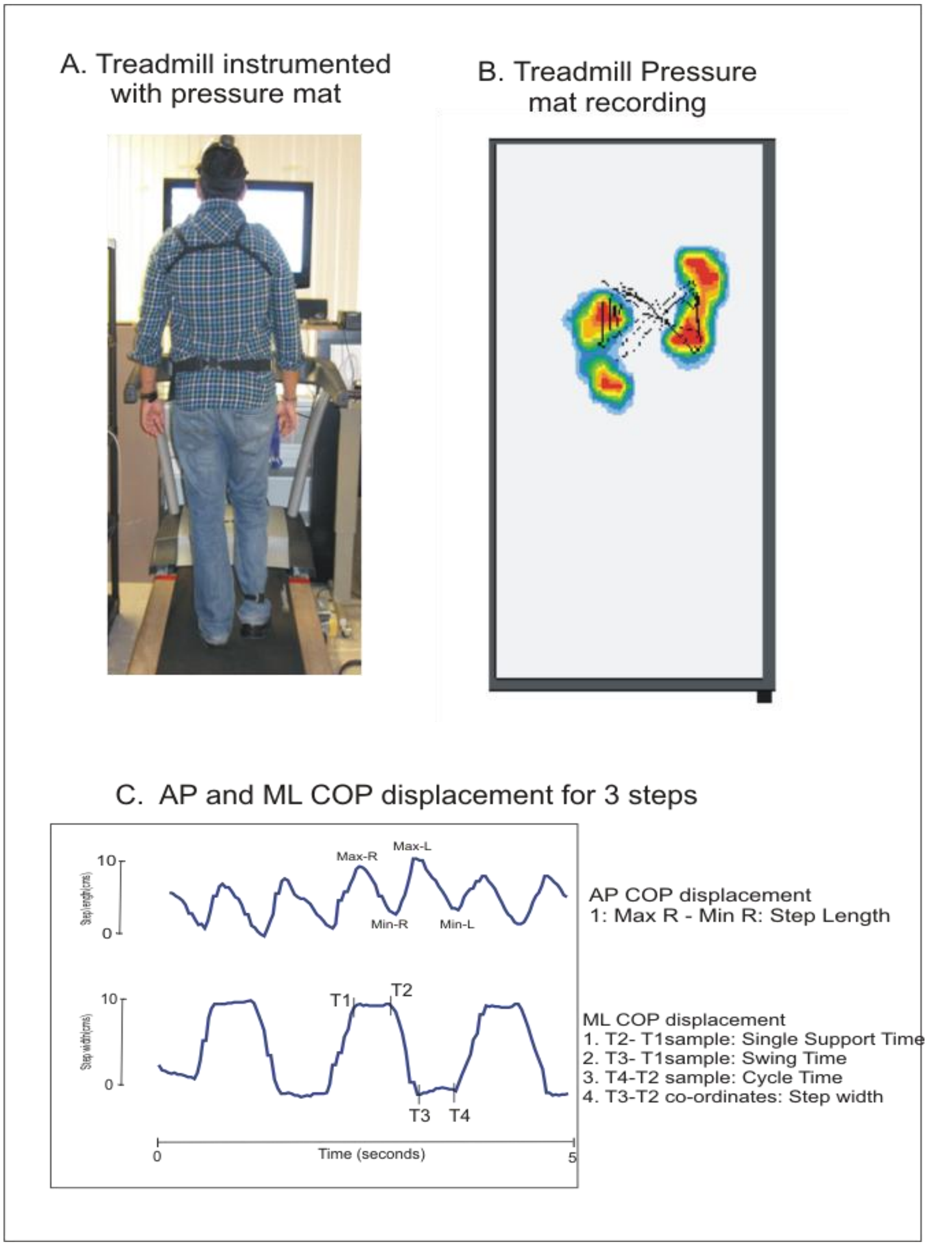
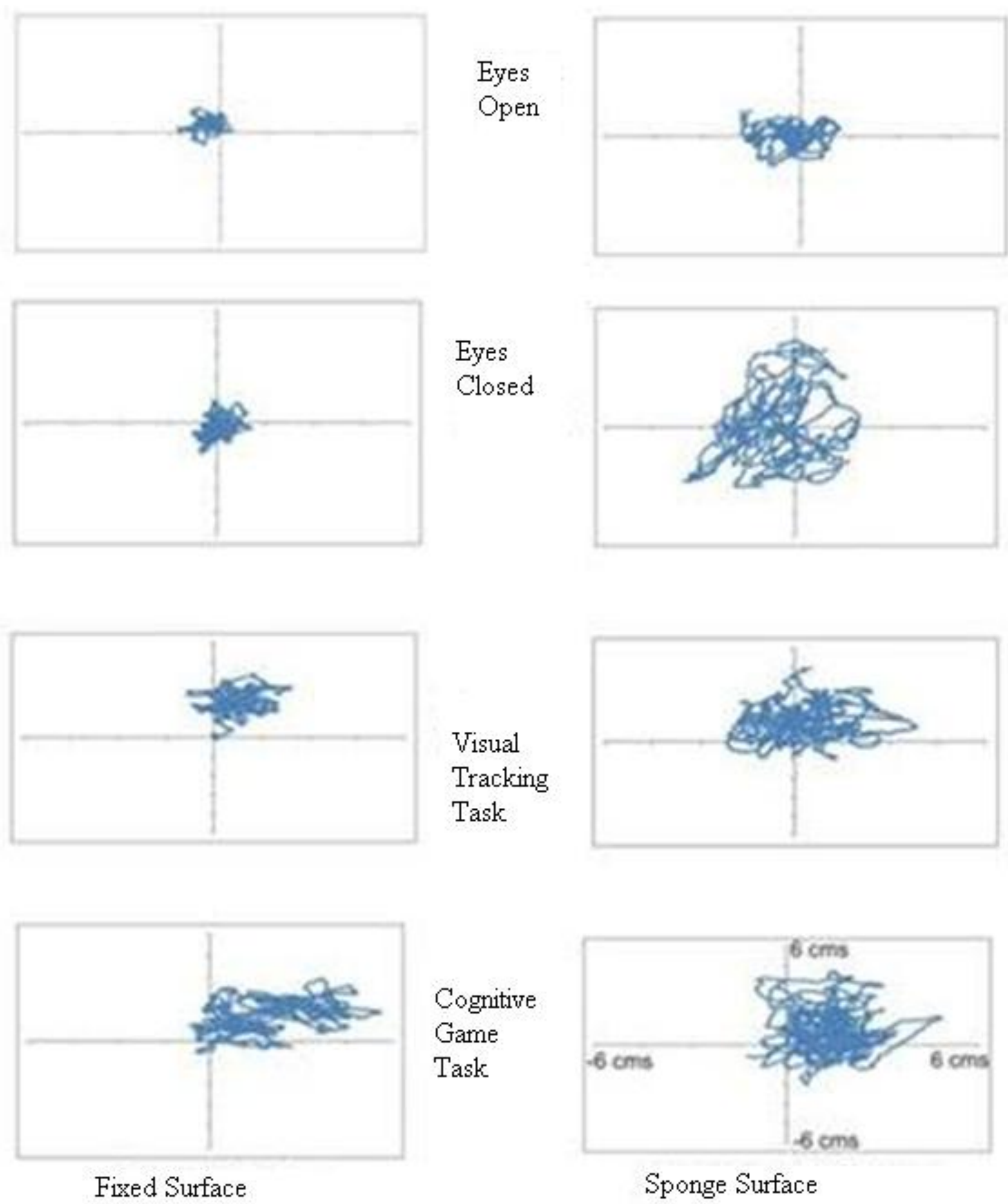


**Figure 2: Represents the individual COP excursions recorded when participants performed single and dual tasks while standing on fixed and sponge surface.**



**Spatial and Temporal Gait Variables**

The treadmill FSA pressure mapping mat was used to derive the COP excursion during walking. The COP excursions were used to derive the various spatial and temporal gait parameters, (Picture 2 and Fig 1 Panel B). The average and Co efficient of Variation for the spatial and temporal gait variables of all the steps were derived and used for the analysis.

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.

Temporal Variables:-

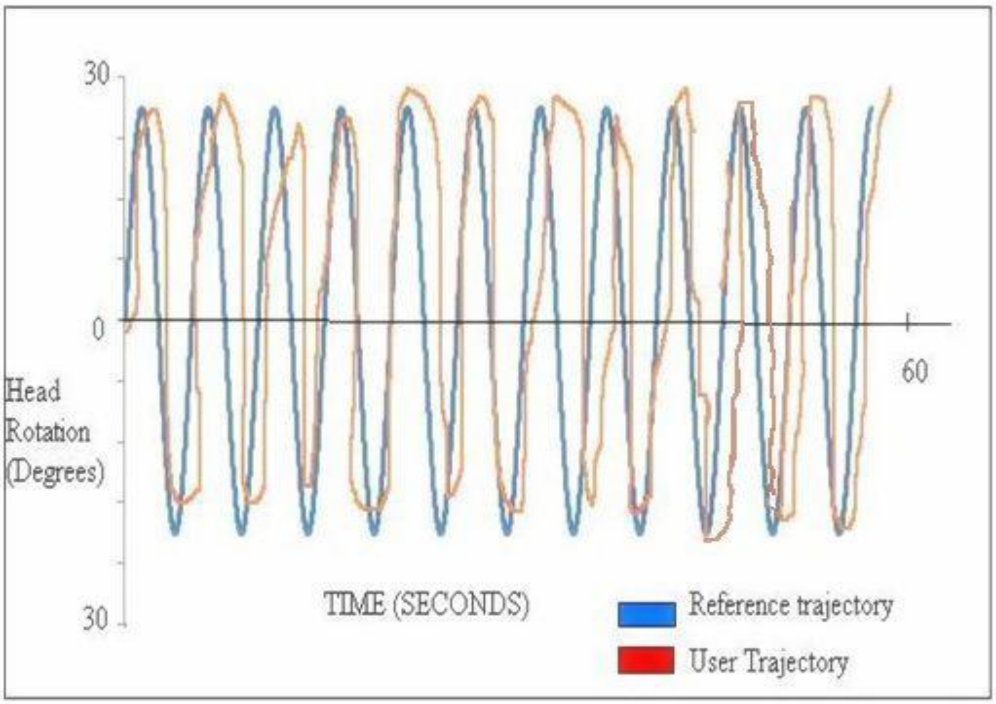
1) Swing time: The amount of time the foot is not in contact with the ground, so there is no pressure available on the mat.
2) Cycle/ Step time: The time taken by one foot from its initial contact of the cycle to the next initial contact of the next gait cycle.

**Head tracking Task Measures and Analysis**

The simultaneous tracking task recorded the coordinates and time intervals of each event of the head tracking task. The user trajectory was recorded as the participants tracked the moving target on the screen and then was compared with the reference trajectory. The computer game based measures such as coordinates of the target reference cursor were evaluated using the

Coefficient of Determination (COD). Figure 3 illustrates the evaluation of the tracking task performance using user and reference trajectories.

**Figure 3: Head tracking task data recording and analysis**

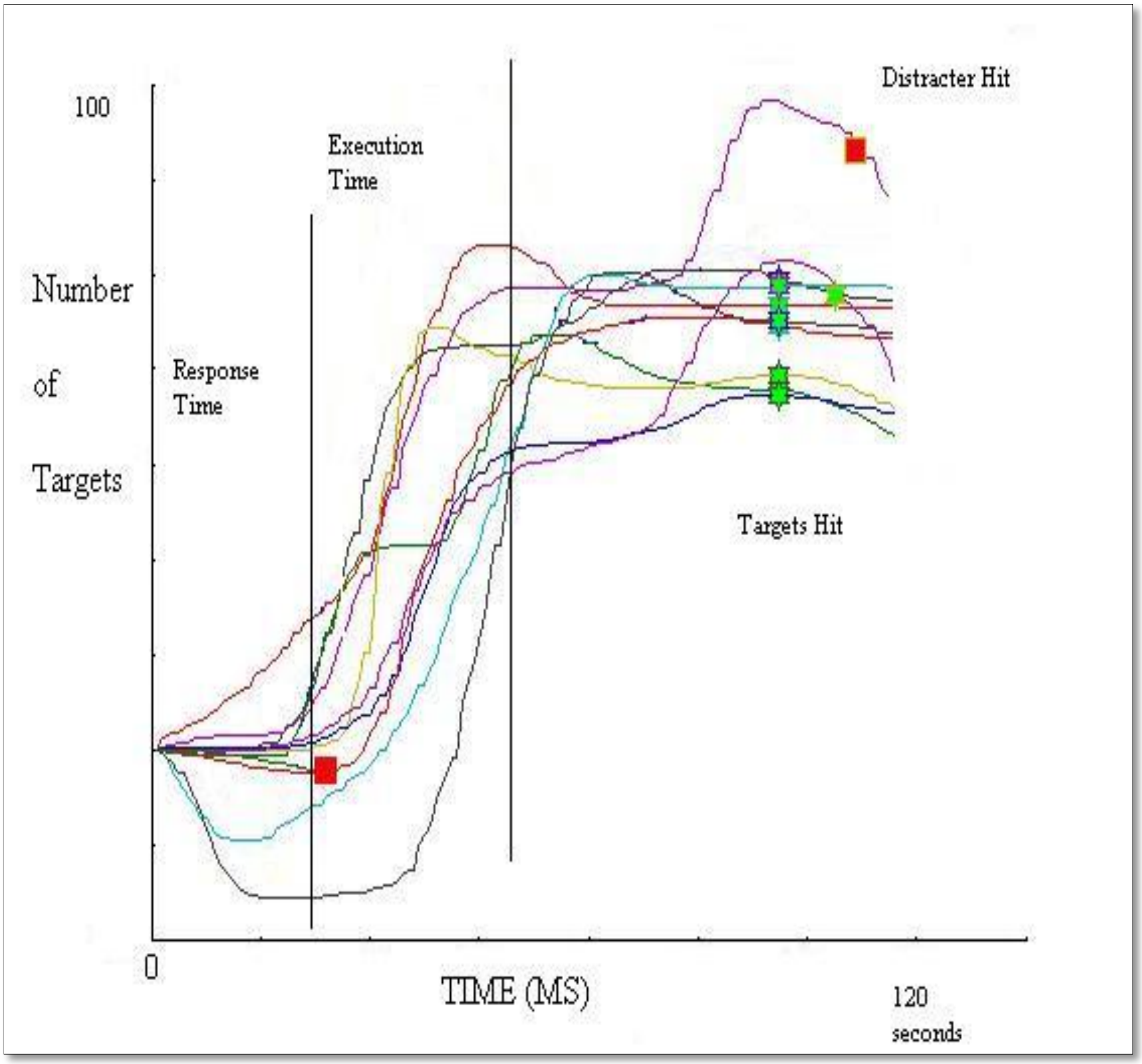


**Cognitive Game Task Performance Measures and Analysis**

Figure 4 below presents the method of extracting the cognitive game task performance measures. Participants tracked the moving target on the screen and visual spatial perception and processing speed of the participants were assessed using the following process measures:

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.

**Figure 4: Cognitive game task data analysis**



### 3.6 Statistical Analysis

Statistical Package for Social Sciences (SPSS- version 20) was used to perform the statistical analysis on the data recorded.

Objective 1

To examine the effects of age (three groups) on performance measures of balance, spatial and temporal gait variables, gaze performance and cognitive performance during single task conditions. One way ANOVA was used to examine the effects of age on

1. RMS COP excursion in AP and ML direction for standing balance,
2. Averages and COV of step width, step length, swing time and step time for spatio-temporal gait parameters,
3. COD for head tracking task performance and
4. Success rate, execution time and response time for cognitive task performance during single task condition.

Objective 2

To examine the effects of aging on Dual Task (DT) performance during standing balance activities. DT included performing the cognitive task.

a. Within group or Random factors: eyes open standing, Cognitive game task

b. Between group or Fixed factors: Age.

Objective 3:

To examine the effects of aging and DT performance on spatio-temporal gait parameters, Dual-task included performing head tracking task at the same time as cognitive task.

1) a. Within group or Random factors: walk alone, Tracking Task,

   b. Between group or Fixed factors: Age.

2) a. Within group or Random factors: walk alone, Cognitive game task

   b. Between group or Fixed factors: Age.

## Chapter 4: Results

In the present study, data of participants from three groups were included (young, old and oldest adults). The TRP protocol was used to record data of the thirty oldest participants while performing single and dual tasks. The comparison data for the other two groups was obtained used from two other studies, (Sakhalkar V., 2013 and Sabapathy S., 2014) which are not yet published). Table 1 presents the demographic data and initial test results for participants from all the three groups. It was observed that as the age increased there was a significant decrease in the performance of the participants. The oldest population showed a poorer performance while performing the tandem walk, six minute walk test, trail making test A and B, and lower scores in the CHAMPS questionnaire.

**Tables 1: Demographic data table showing baseline performances of all three age groups.**

| Demographic Data | Young Adults | Older Adults | Oldest |
|---|---|---|---|
| Age | 26.7±2 | 61.4± 4.4 years | 75.5±4.5 years |
| Gender (Male: Female) | 2:1 | 26: 4 | 18:14 |
| Tandem Walk Grade | 3.93± 1.2 (Fair) | 2.75±0.48 (poor to fair) | 1.8±1.0 (poor) |
| Six Minute Walk Test | N/A | 562 (m) | 510 (m) |
| CHAMPS Intensity Frequency | N/A | 1.29±0.39<br>1.23±0.46 | 1.01±0.5<br>1.01±.3 |
| Trail Making Test A<br><br>Trail Making Test B | N/A<br><br>N/A | 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=12.1±9.2 | Total Time= 77± 75 (s)<br>Number of errors= 3.09± 1.5<br>Total Time= 110.79± 89.3 (s)<br>Number of errors=4.3±1.8 |

### 4.1 Effects of age on single task performance measures; standing (COP excursion), spatial and temporal gait variables (Normal Walking) and head tracking and cognitive task performances

Table 2a presents statistical results on the effects of Age on RMS of COP in AP and ML directions while standing on a fixed surface with eyes open, eyes closed and standing on a sponge surface with eyes open. Figure 5 below illustrates the group means and standard error of the mean of RMS COP AP and ML excursions of young, older and oldest adults during standing on a fixed and sponge surface. No significant effect of age was observed on COP excursions when all the participants were asked to stand on fixed surface with eyes open, with eyes closed and standing on sponge eyes open. During standing on sponge surface with eyes closed, a significant number of oldest participants had a fall (n=17). Two of the old adults fell during this task where as the young adults did not present with any falls. Thus this data could not be analyzed.

Table 2b presents the statistical results for effect of age on spatial and temporal gait variables during normal walking. Figure 6 shows the group means and standard error of the mean of spatio-temporal gait parameters in young, older and oldest adults during normal walking. There was no significant effect of age observed on average step width during normal walking. As evident in figure 6, a significantly lower average Step length was observed in the oldest population as compared to both young and older group. There was a significant higher COV of Swing time and Step time gait variables while normal walking in oldest adults as compared to other two groups.

Table 2c presents the statistical results for effects of increase in age on head tracking task performance measure (COD). Figure 8B below shows the group means and the standard error of the mean of COD recorded during the head tracking task performed while standing. As evident in figure 8b, a significant decrease in the COD of the head tracking task performance was observed in the oldest participants as compared to young and old adults.

Table 2d presents the statistical results for effects of increase in age on cognitive game task performances. Figure 9B demonstrates the percentage of success rate response time and execution time of the young, older and oldest adults while performing cognitive game tasks during standing. Figure 9B clearly shows a significantly lower performance in cognitive game task performance measures (i.e. Success Rate, Response Time and Execution Time) in the oldest participants as compared to the young and older adults.

**Table 2a: Results of One way ANOVA presenting the main effects of Age on RMS of COP in AP and ML directions while standing on a fixed surface with eyes open, eyes closed and standing on a sponge surface with eyes open.**

| **Eyes open on fixed surface** | **Age** |
|---|---|
| COP - AP | NS |
| COP – ML | NS |
| **Eyes closed on fixed surface** | **Age** |
| COP - AP | NS |
| COP - ML | NS |
| **Eyes open on sponge surface** | **Age** |
| COP - AP | NS |
| COP - ML | NS |

NS: Not Significant ($p > 0.05$); significant $p<0.05$; df: degrees of freedom

**Table 2b: Results of One way ANOVA for presenting the main effects of Age on the average and COV of spatial and temporal gait variables**

| Variable | Age |
|---|---|
| Step width Average | NS |
| Step width COV | NS |
| Step Length Average | $p < 0.01$<br>$f = 4.483$<br>$df = 2$ |
| Step Length COV | $p < 0.01$<br>$f = 6.620$<br>$df = 2$ |
| Swing Time COV | $p < 0.01$<br>$F = 9.328$; $df = 2$ |
| Step Time COV | $p < 0.01$<br>$f = 36.294$<br>$df = 2$ |

NS: Not Significant ($p > 0.05$); significant $p < 0.05$; df: degrees of freedom

**Table 2c: Results of a One way ANOVA for the main effects of Age on the head tracking game task performance measures**

| Head tracking Task | Age |
|---|---|
| COD | P =.002<br>F= 6.484; df= 2 |

NS: Not Significant (p> 0.05); significant p<0.05; df: degrees of freedom

**Table 2d: Results of a One way ANOVA for presenting the main effects of Age on cognitive game task performance measure**

| Cognitive Game Task | Age |
|---|---|
| Success Rate | p =.000<br>F= 9.536; df= 2 |
| Response Time | p =.003<br>F= 6.043; df= 2 |
| Execution Time | NS |

NS: Not Significant (p> 0.05); significant p<0.05; df: degrees of freedom

**4.2 Effects of cognitive game task performance and age on standing balance (Stability) while dual tasking.**

Table 3 present's the statistical results of the effects of cognitive game task and age on RMS COP excursions while dual tasking. Figure 5 below illustrates the group mean and standard error of the mean for RMS COP excursions in AP and ML direction on fixed and sponge surfaces during single and dual tasking in the three age groups. A significant effect of cognitive task load was observed on RMS COP excursions in AP and ML direction. A significant effect of age was observed on the RMS COP excursions. As evident in figure 5 there was a significant increase in RMS COP excursions in AP and ML direction while performing the cognitive task during standing on a fixed and sponge surface while dual tasking in all three age groups. There was a significant increase in RMS COP in AP and ML direction in the oldest group as compared to both young and older adults while performing the cognitive game task while standing on a fixed and sponge surface. There was no significant interaction effect of cognitive task load and age on RMS COP excursions while performing a cognitive task during standing.

**Figure 5: Group Means and standard error of mean of COP excursions of young, older and oldest adults during different cognitive game tasks**

**A: RMS COP AP excursions while standing on a fixed surface.**

**B: RMS COP excursions in ML while standing on a fixed surface.**

**C: RMS COP AP excursions while standing on a sponge surface.**

**D: RMS COP excursions in ML while standing on a sponge surface.**

Fig 05

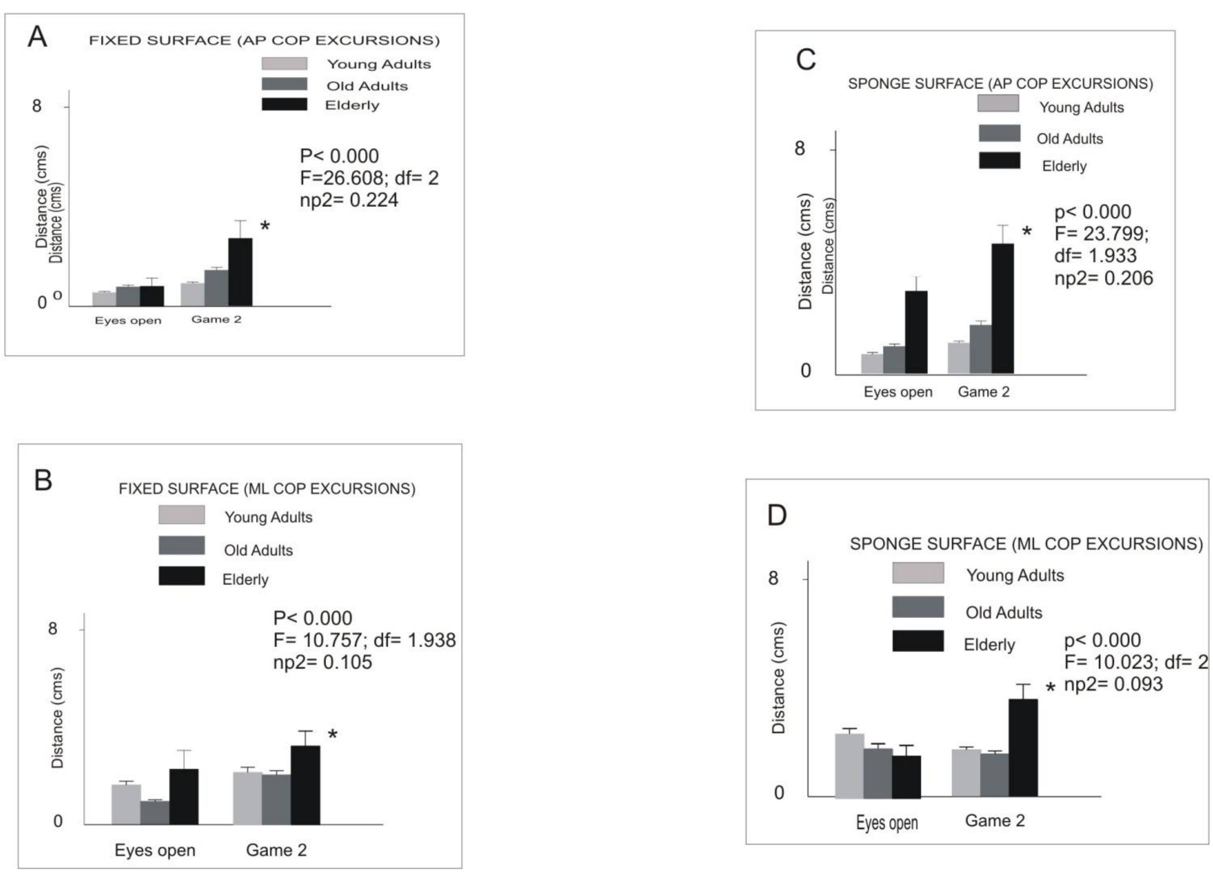


**Table 3: Results of Two way ANOVA for the effects of the cognitive game task and age on standing balance while dual tasking (RMS COP in AP and ML directions):**

| COP Excursions (AP) | Cognitive Task load | Age | Interaction |
|---|---|---|---|
| Fixed | P< 0.000<br>F=26.608; df= 2<br>$np^2$= 0.224 | p <0.000<br>F= 10.021; df= 2<br>$np^2$= 0.875 | NS |
| Sponge | p< 0.000<br>F= 23.799; df= 1.933<br>$np^2$= 0.206 | p <0.000<br>F= 14.272; df= 2<br>$np^2$= 0.237 | NS |
| **COP Excursions (ML)** | **Cognitive Task Load** | **Age** | **Interaction** |
| Fixed | P< 0.000<br>F= 10.757; df= 1.938<br>$np^2$= 0.105 | p <0.074<br>F= 2.674; df=2<br>$np^2$= 0.055 | NS |
| Sponge | p< 0.000<br>F= 10.023; df= 2<br>$np^2$= 0.093 | p <0.040<br>F= 3.328; df= 2<br>$np^2$= 0.067 | NS |

NS: Not Significant (p> 0.05); significant p<0.05; df: degrees of freedom; $np^2$: Effect size

### 4.3 Effect of head tracking task performance and age on Spatial and Temporal gait variables while dual tasking

#### 4.3.1 Spatial Gait Variables

Table 4 and Table 5 below present the statistical results for effects of the head tracking task load and age on the means and standard errors of means of spatial gait variables during dual tasking respectively. Figure 6 (A to D) demonstrates the group means and standard error of the mean for the average and COV of spatial gait variables during normal walking and while performing the head tracking task.

There was no significant effect of the head tracking task load on average step width during dual task walking. There was a significant effect of head tracking task load on average step length. As evident in figure 6c, the average step length decreased significantly when the head tracking task was performed during walking as compared to the walk alone condition. There was a significant effect of age on average step width as well as average step length while dual task walking with the head tracking task. As evident in figure 6b and 6d the average step width decreased significantly in the oldest population as compared to the other two groups where as average step length decreased significantly between the young, older and the oldest population. No significant interaction effect was observed on the average step width while performing the head tracking task during walking. There was a significant interaction between the effect of age and dual tasking on average step length. During the dual tasking condition the decrease in average step length was significant in all three age groups.

There was a significant effect of the head tracking task load on the COV of step length but not step width. There was a significant effect of age on the COV of step width from young to older adults but not from older adults to the oldest population while performing the head tracking task during walking. There was a significant effect of age on the COV of step length from older adults to the oldest population but not from young to older population, while performing the head tracking task during walking. No significant interaction effect was observed on the COV of step length and step width as the age and head tracking load increased.

**Table 4: Statistical results of the effects of performing the head tracking task and age on the average of spatial gait variables during dual tasking.**

| Spatial Variables (means) | Head tracking Task Load | Age | Interaction |
|---|---|---|---|
| Step width | NS | p .034<br>f= 3.495; df= 2<br>$np^2$= .071 | NS |
| Step length | p .000<br>f= 26.180; df= 2<br>$np^2$= .222 | p .000<br>f= 49.777; df= 2<br>$np^2$= .520 | p .077<br>f= 2.142; df= 4<br>$np^2$= .044 |

NS: Not Significant ($p > 0.05$); significant $p < 0.05$; df: degrees of freedom; $np^2$: Effect size

**Table 5: Statistical results of effects of performing the head tracking task and age on COV in spatial gait variables during dual tasking.**

| Spatial Variables (COV) | Head tracking Task Load | Age | Interaction |
|---|---|---|---|
| Step width | NS | p .002<br>f= 6.631;<br>$np^2$= .126 | NS |
| Step length | p .000<br>f= 26.180; df= 2<br>$np^2$= .222 | p .000<br>f= 36.405; df= 2<br>$np^2$= .442 | NS |

NS: Not Significant ($p > 0.05$); Significant $p < 0.05$; df: degrees of freedom; $np^2$: Effect size

### 4.3.2 Temporal gait variables

Table 6 and Table 7 illustrates the statistical results for the effects of head tracking task load and age on average and COV of temporal gait variables during dual tasking respectively. Figure 6 (e-h) below shows the group means and standard error of mean for the average and COV of temporal gait variables during normal walking and while performing the head tracking task in the three age groups.

There was a significant effect of the head tracking task load on the average swing time during dual task walking. As evident in figure 6e, a significant decrease in the average swing time was seen while performing the head tracking task during walking. There was also a significant effect of head tracking task load on average step time. As evident in figure 6g the average step time increased significantly when the head tracking task was performed during walking as compared to the walk alone condition. There was a significant effect of age on average swing time as well as average step time in the three age groups while performing the head tracking task during walking. As evident in figure 6e and 6g the average swing time decreased significantly in the oldest population, where as average step time increased significantly as compared to the other two groups, but there was no significant difference observed between the young and the older population. There was a significant interaction between the effect of age and dual tasking on average swing time as well as on average step time. During dual tasking there was a significant increase in the average swing time and average step time in all three age groups.

There was a significant (increased) effect of head tracking task load on the COV of swing time as well as step time in all three age groups while performing the head tracking task during walking. There was a significant effect of age on the COV of swing time and step time in the three populations while performing the head tracking task during walking. As shown in Figure 6f and 6h the COV of swing time was significantly higher in the older and oldest population as compared to the young group but there was no significant difference observed between the older and the oldest population. The COV of step time was significantly greater in the oldest population compared to the other two age groups while performing dual task walking with the head tracking task. No significant interaction effect was observed on the COV of swing time as age and head tracking load increased. In contrast, there was a significant interaction between the effect of dual tasking and age on the COV of step time while performing the head tracking task while walking.

**Table 6: Statistical results of the effects of performing the head tracking task and age on average temporal gait variables during dual tasking.**

| Temporal variable (Mean) | Head tracking Task | Age | Interaction |
|---|---|---|---|
| Swing Time | p .012<br>f= 5.517; df= 1.362<br>$np^2$= .057 | p .000<br>f= 666.845; df= 2<br>$np^2$= .935 | p .003<br>f= 5.235; df= 2.725<br>$np^2$= .102 |
| Step Time | p .000<br>f= 70.962; df= 1.424<br>$np^2$= .435 | p .000<br>f= 205.242; df= 2<br>$np^2$= .817 | p .000<br>f= 65.057; df= 2.849<br>$np^2$= .586 |

Significant: $p<0.05$; df: degrees of freedom; $np^2$: Effect size

**Table 7: Statistical results of effects of performing the head tracking task and age on the COV of the temporal gait variables during dual tasking.**

| Temporal variable (COV) | Head tracking Task | Age | Interaction |
|---|---|---|---|
| Swing Time | p .02<br>f= 2.037; df= 2<br>$np^2$= .022 | p .000<br>f= 22.084; df= 2<br>$np^2$= .324 | NS |
| Step Time | p .000<br>f= 33.958; df= 2<br>$np^2$= .270 | p .000<br>f= 36.294; df= 2<br>$np^2$= .441 | p .000<br>f= 32.686; df= 2.049<br>$np^2$= .415 |

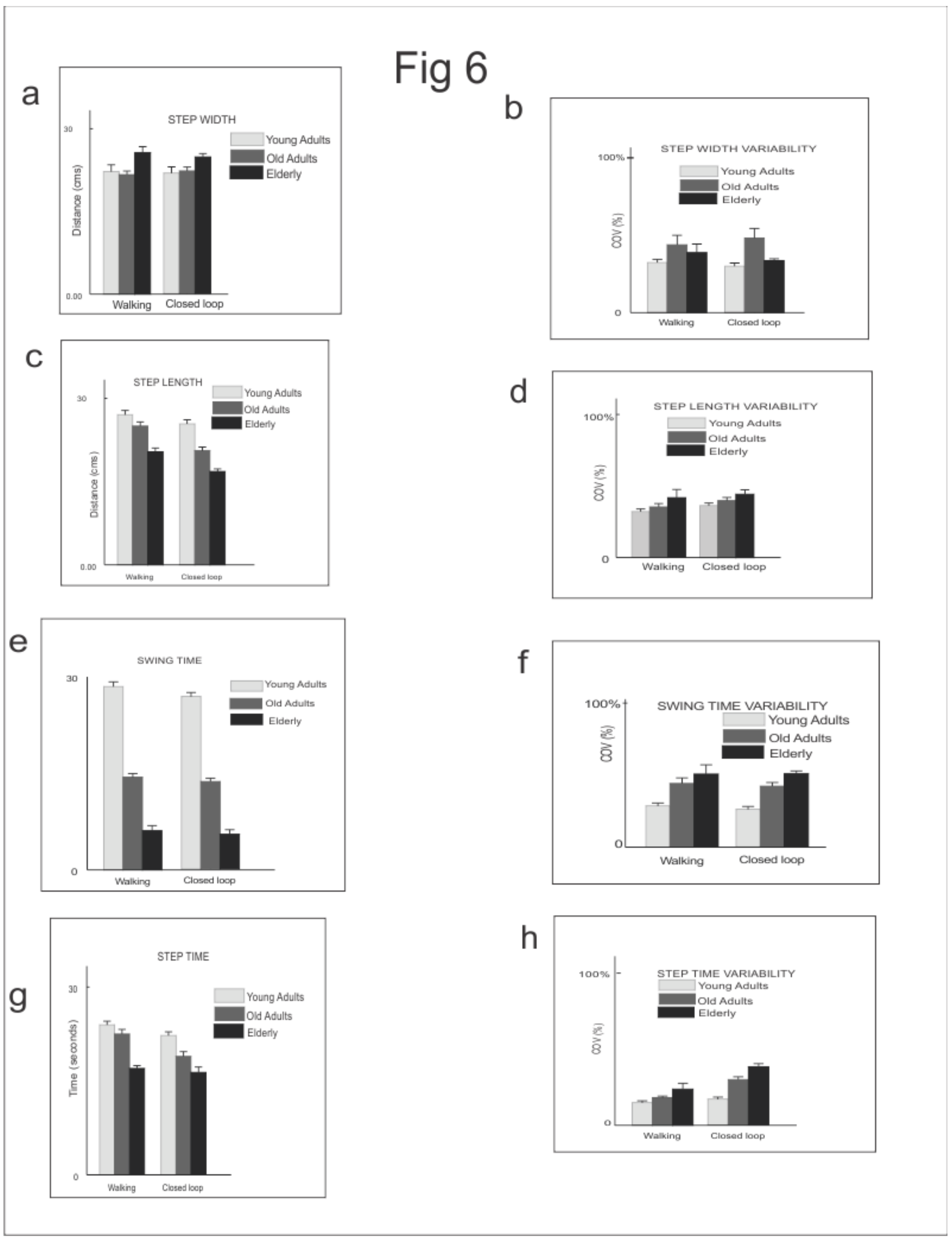
NS: Not Significant (p> 0.05); Significant: p<0.05; df: degrees of freedom; $np^2$: Effect size

**Figure 6: Group mean and Standard error of mean for various spatial and temporal gait variables (Averages and COV) during head tracking task performance in young and old and oldest adults.**

**a: Average step width; b: Step width variability; c: Average Step length;**

**d: Step length variability; e: Average Swing time; f: Swing time variability**

**g: Average Step time; h: Step time variability**



### 4.4 Effect of performing a cognitive task and age on Spatial and Temporal gait variables while dual tasking

#### 4.4.1 Spatial gait parameters

Table 8 and Table 9 below present the statistical results of effects of performing a concurrent cognitive task and age on the average and COV of spatial gait variables during dual tasking respectively. Figure 7 (a-d) demonstrates the group means and standard error of the mean of the average and COV for the spatial gait variables during normal walking and while performing the cognitive game task.

There was a significant effect of cognitive task load on average step width as well as average step length during dual task walking. As evident in Figure 7a and 7c average step width and average step length decreased significantly when the cognitive task was performed during walking as compared to the walk alone condition. There was a significant effect of age on average step width as well as average step length while performing the cognitive task during walking. The average step width decreased significantly between the older and the oldest group but not between the young and older groups. Average step length decreased significantly in all the three populations. No significant interaction effect was observed on average step width while performing the cognitive task during walking. There was a significant interaction between the effect of age and dual tasking on average step length. During the dual tasking condition there was a significant decrease in average step length in all three age groups.

There was a significant effect of cognitive task load on the COV of step width as well as step length during dual task walking. As evident in figure 7b and 7d the COV of step width and step length increased significantly when the cognitive task was performed during walking as compared to the walk alone condition. There was a significant effect of age on the COV of step width from young to older adults and from older adults to the oldest population while performing the cognitive task during walking. There was a significant effect of age on the COV of step length from older adults to the oldest population but not from the young to older population while performing the cognitive task during walking. A significant interaction effect was observed on COV of step length and step width as age and cognitive task load increased.

**Table 8: Statistical results of effects of performing a cognitive game task and age on spatial gait variables during dual tasking.**

| Spatial Variables (Average) | Cognitive Game Task | Age | Interaction |
|---|---|---|---|
| Step width | p< 0 .01<br>f= 6.012; df= 1.825<br>$np^2$= .061 | p< 0 .01<br>f= 3.495; df= 2<br>$np^2$= .071 | NS |
| Step length | p< 0 .01<br>f= 23.507; df= 1.912<br>$np^2$= .204 | p< 0 .01<br>f= 44.483; df= 2<br>$np^2$= .492 | p< 0 .01<br>f= 6.806; df= 3.823<br>$np^2$= .129 |

NS: Not Significant (p> 0.05); Significant: p<0.05; df: degrees of freedom; $np^2$: Effect size

**Table 9: Statistical results of effects of performing the cognitive game task and age on the COV of spatial gait variables during dual tasking.**

| Spatial Variables (COV) | Cognitive Game Task | Age | Interaction |
|---|---|---|---|
| Step width | $p < 0.01$<br>f= 7.667; df= 2<br>$np^2$= .077 | $p < 0.01$<br>f= 25.600; df= 2<br>$np^2$= .358 | $p < 0.01$<br>f= 2.666; df= 4<br>$np^2$= .055 |
| Step length | $p < 0.01$<br>f= 7.979; df= 1.494<br>$np^2$= .082 | $p < 0.01$<br>f= 64.620; df= 2<br>$np^2$= .592 | $p < 0.01$<br>f= 2.969; df= 2.988<br>$np^2$= .063 |

NS: Not Significant ($p > 0.05$); Significant: $p < 0.05$; df: degrees of freedom; $np^2$: Effect size

### 4.4.2 Temporal Gait Variables

Table 10 and Table 11 below present the statistical results of effects of cognitive task load and age on means and COV of temporal gait variables during dual tasking respectively. Figure 7 (e-h) illustrates the group means and standard error of the mean of the average and COV of temporal gait variables during normal walking and while performing the cognitive game task.

There was a significant effect of cognitive task load on the average swing time during dual task walking. As evident in figure 7e a significant decrease in the average swing time was seen while performing the cognitive task during walking. There was a significant effect of cognitive task load on average step time. Figure 7g shows that the average step time was decreased significantly when the cognitive task was performed during walking as compared to the walk alone condition. There was a significant effect of age on average swing time as well as average step time in the three age groups while performing the cognitive task during walking. As evident in figure 7e and 7g, the average swing time as well as the average step time decreased significantly in the oldest population as compared to the other two groups but there was no significant difference observed between the young and the older population. There was no significant interaction between the effect of age and dual tasking on average swing time but there was a significant interaction between the effect of age and dual tasking on average step time. During dual tasking there was a significant decrease in average step time in all age groups.

There was a significant effect of cognitive task load on the COV of swing time and step time in that they increased significantly in all three age groups while performing the cognitive task during walking. There was also, a significant effect of age on COV of swing time and step time in all three populations while performing the cognitive task during walking. Figure 7f and 7h shows the COV of swing time was significantly higher in the older and oldest population as compared to the young group but there was no significant difference observed between the older and the oldest population. The COV of step time was significantly greater in the oldest population compared to the other two age groups while performing dual task walking with the cognitive task. No significant interaction effect was observed on the COV of swing time as the age and cognitive load increased. In contrast to this, there was a significant interaction between the effect of dual tasking and age on the COV of step time during the performance of the cognitive task while walking.

**Table 10: Statistical results of effects of performing the cognitive game task and age on average temporal gait variables during dual tasking.**

| Temporal variable (Average) | Cognitive Task | Age | Interaction |
|---|---|---|---|
| Swing Time | p < 0.01<br>f= 2.384; df= 1.026<br>$np^2$= .025 | P< 0.01<br>f= 9.061; df= 2<br>$np^2$= .165 | NS |
| Step Time | p< 0.01<br>f= 63.972; df= 1.817<br>$np^2$= .410 | p< 0.01<br>f= 171.609; df= 2<br>$np^2$= .789 | p< 0.01<br>f= 59.853; df= 3.634<br>$np^2$= .565 |

NS: Not Significant (p> 0.05); Significant: p<0.05; df: degrees of freedom; $np^2$: Effect size

**Table 11: Statistical results of effects of performing the cognitive game task and age on the COV of temporal gait variables during dual tasking.**

| Temporal variable (COV) | Cognitive Task Load | Age | Interaction |
|---|---|---|---|
| Swing Time | $p < 0.01$<br>$f = 10.923$; $df = 1.979$<br>$np^2 = .106$ | $p < 0.01$<br>$f = 39.760$<br>$np^2 = .464$<br>$df = 2$ | NS |
| Step Time | $p < 0.01$<br>$f = 31.741$; $df = 1.025$<br>$np^2 = .257$ | $p < 0.01$<br>$f = 36.322$; $df = 2$<br>$np^2 = .441$ | $p < 0.01$<br>$f = 32.615$; $df = 4$<br>$np^2 = .415$ |

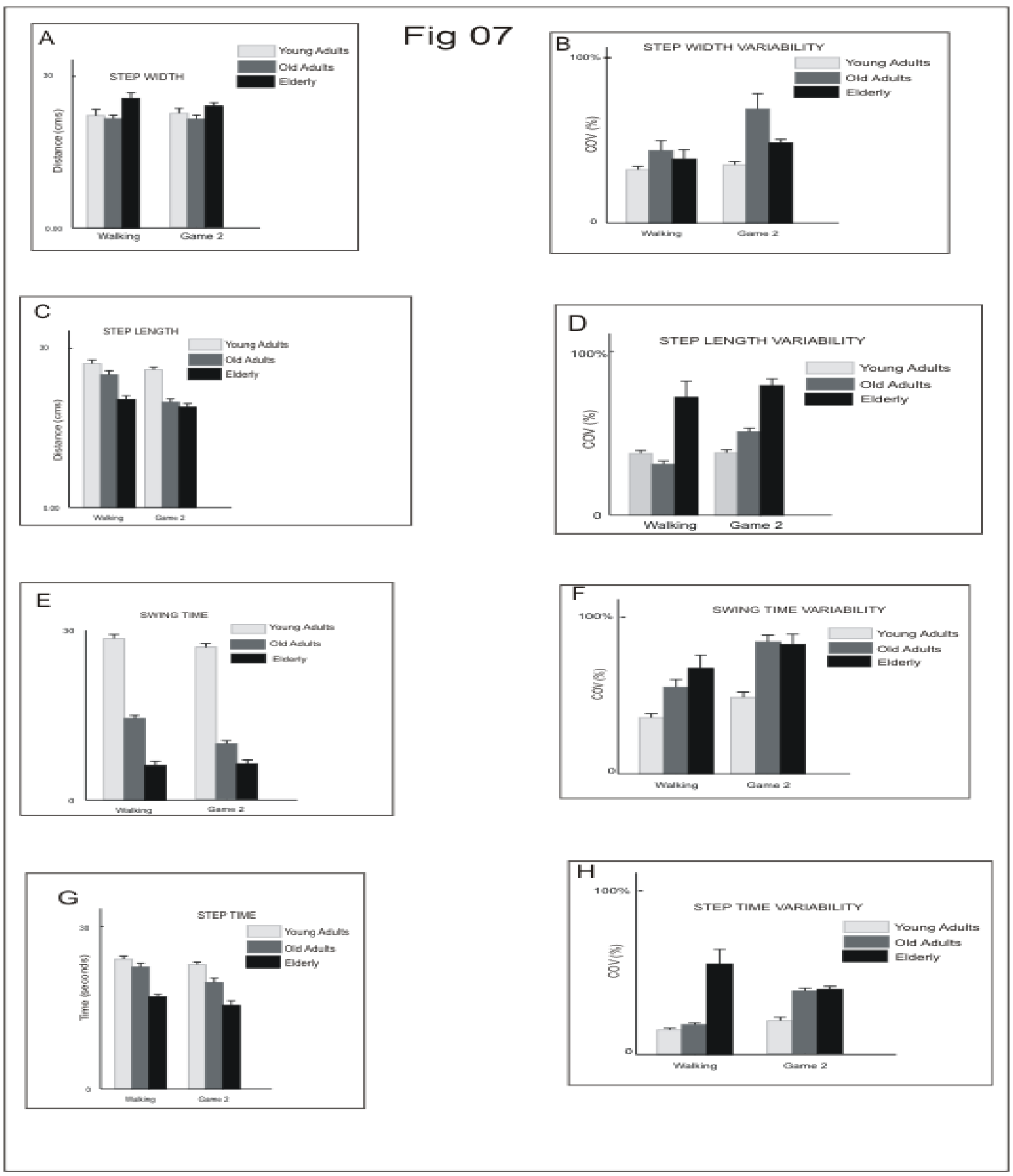
NS: Not Significant ($p > 0.05$); Significant: $p < 0.05$; df: degrees of freedom; $np^2$: Effect size

**Figures 7**: **Group means and Standard error of the mean for various spatial and temporal gait variables (Averages and COV) during cognitive game task performance in young and old and oldest adults.**

**A: Average step width; B: Step width variability; C: Average Step length**

**D: Step length variability; E: Average Swing time; F: Swing time variability**

**G: Average Step time; H: Step time variability**



### 4.5 Effect of increase in physical load and age on head tracking task performances while dual tasking

Table 12 below presents the statistical results of the effects of performing the head tracking task during standing and walking. Figure 8a illustrates the data of an individual performance of the head tracking task while standing on a fixed surface and while walking on a treadmill. It is evident that the sinusoidal trajectories become remarkably scattered when the head tracking task was performed while walking. Figure 8b presents the group means and the standard error of the mean of the COD recorded during performance of the head tracking task while standing as well as walking. There was a significant decrease in head tracking task performance when the physical load was increased from standing on fixed surface to walking in all three age groups. There was a significant decrease in head tracking task performance from young to older adults and from older adults to the oldest population while performing the head tracking task during walking. Young adults performed significantly better than the older and oldest adults while dual tasking. No significant interaction effect was observed on the coefficient of determination of the head tracking task.

**Table 12: Statistical results of the effects of the performing the head tracking task during standing and walking.**

| Head tracking Task | Physical Load | Age | Interaction |
|---|---|---|---|
| COD | $p< 0.01$<br>$f= 29.708$; $df= 2$<br>$np^2= .244$ | $p< 0.01$<br>$f= 23.997$; $df= 2$<br>$np^2= .343$ | NS |

NS: Not Significant ($p> 0.05$); Significant: $p<0.05$; df: degrees of freedom; $np^2$: Effect size

**Figure 8a**: **Data of an individual performing the head tracking task while standing on the fixed surface and while walking on the treadmill.**

Fig 8a

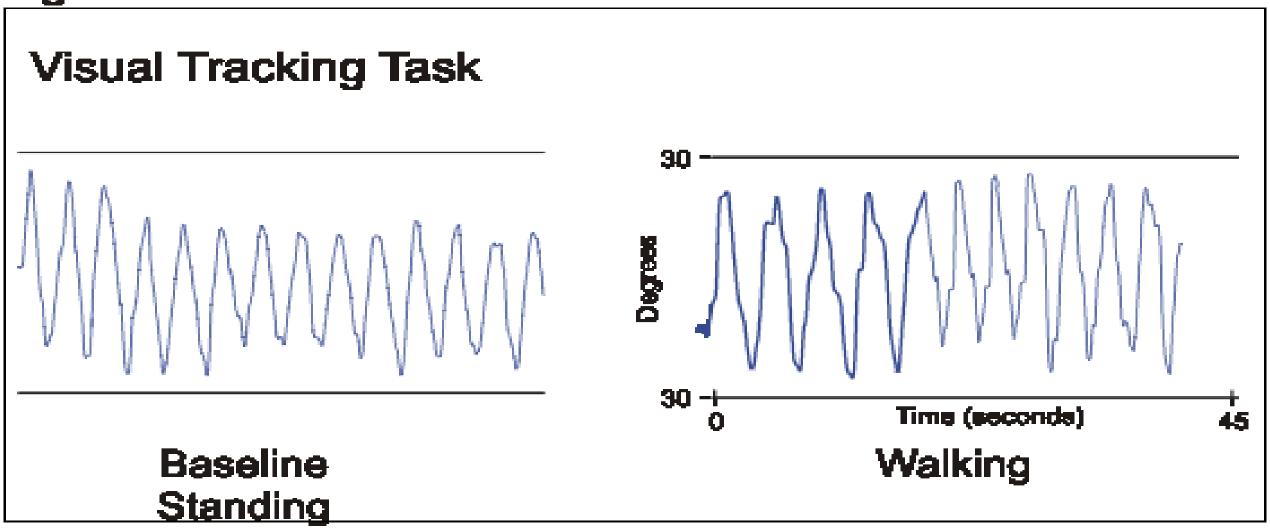
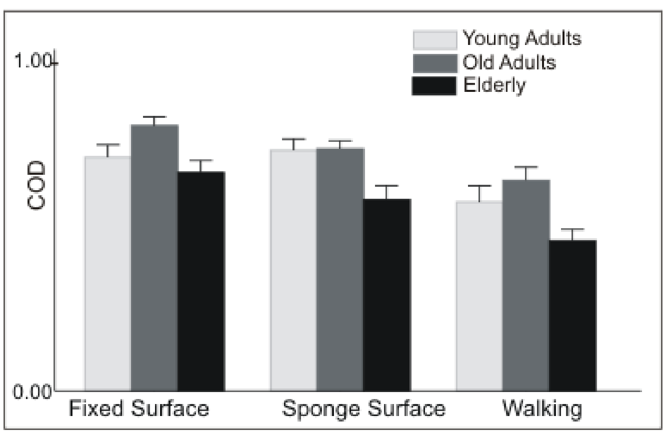



**Figure 8b**: **Group means and the standard error of mean of the COD recorded during the head tracking task performed while standing as well as while walking.**

Fig 8b



**4. 6 Effects of an increase in physical load and age on cognitive game task performances while dual tasking**

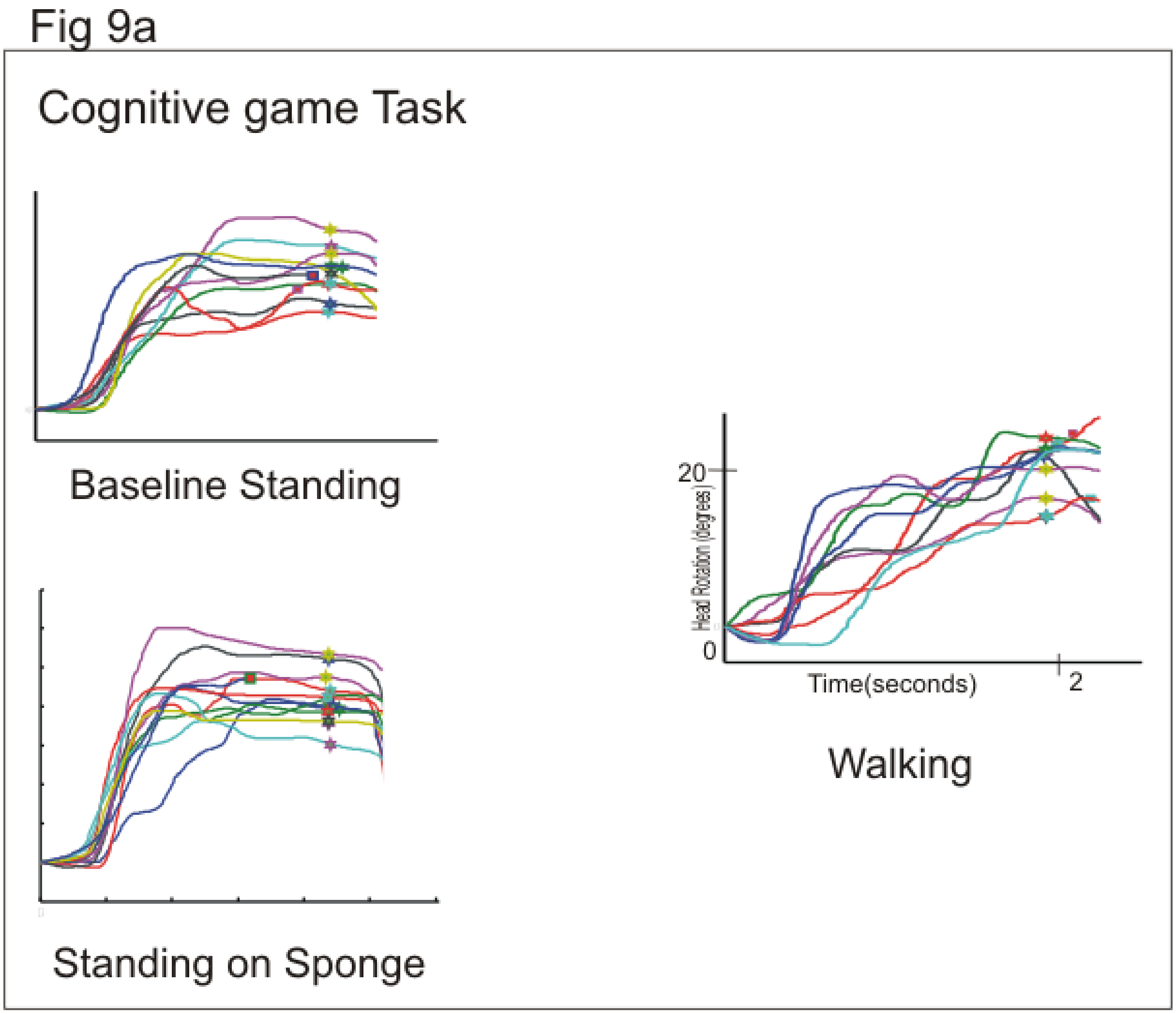
Table 13 presents statistical results of the effects of performing the cognitive task during standing and walking. Figure 9a shows an individual participant performance of the cognitive game task during standing on a fixed surface, sponge surface and while walking. When the participants performed the cognitive game task while standing on the fixed and sponge surface there was a regular pattern in the head movement (i.e. consistent onset period and similar plateau phase). Hence, the participant took less time to get the paddle to the required position (Response Time) and stayed longer to complete the task (Execution Time). During walking, the movement trajectories are irregular and dispersed, it has no regular onset period and plateau phase. Hence, there was increase in Response Time and decrease in Success Rate. Figure 9b presents the group means and standard error of the mean of cognitive game task performance measures during standing and while walking.  As evident in Figure 9b, there was a significant effect of the increase in physical load on the cognitive task performance. There was a significant decrease in Success rate as well as Response time in the oldest participants as opposed to the young and older adults when the physical load was increased. No significant effect of increase in physical load was observed on Execution Time while dual tasking. There was a significant effect of age that caused a significant decrease in cognitive game task performance measures from young to older adults and from older adults to the oldest population while performing the cognitive game task during walking. A significant interaction effect was observed on Success rate and Response time when age and physical task load was increased. The interaction between the effect of age and of the dual task condition decreased the Success rate and increased the Response time significantly.

**Table 13: Statistical results of the effects of performing the cognitive task during standing and walking.**

| Cognitive Task Performances | Physical load | Age | Interaction |
|---|---|---|---|
| Success Rate | $p < 0.01$<br>$f = 12.736$; $df = 1.993$<br>$np^2 = .122$ | $p < 0.01$<br>$f = 24.716$; $df = 2$<br>$np^2 = .350$ | $p < 0.01$<br>$f = 6.436$ ; $df = 3.987$<br>$np^2 = .123$ |
| Reponses Time | $p < 0.01$<br>$f = 2.428$; $df = 2$<br>$np^2 = .026$ | $p < 0.01$<br>$f = 27.047$; $df = 2$<br>$np^2 = .370$ | $p < 0.02$<br>$f = 2.284$; $df = 4$<br>$np^2 = .047$ |
| Execution Time | NS | NS | NS |

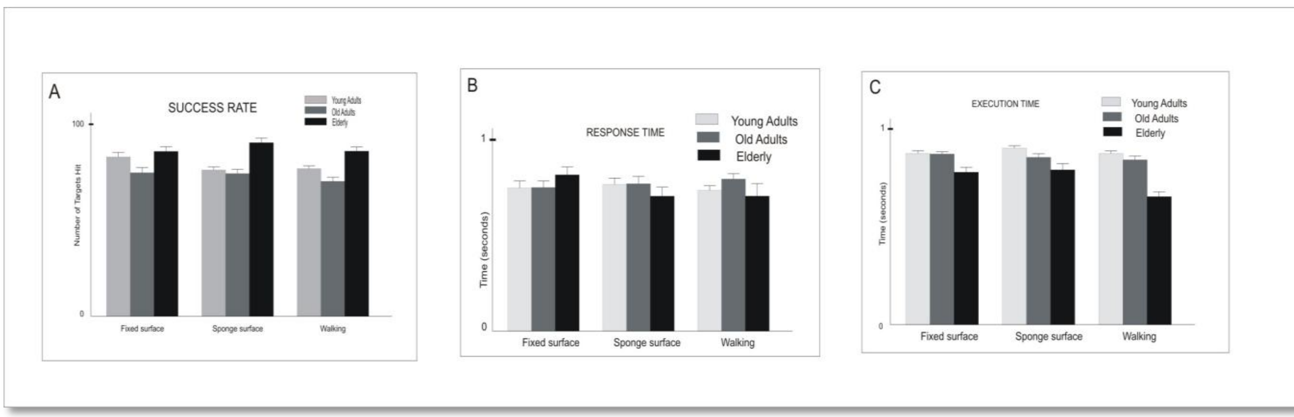
NS: Not Significant ($p > 0.05$); Significant: $p < 0.05$; df: degrees of freedom; $np^2$: Effect size

**Figure 9a: The Cognitive game task performances during standing and while walking.**



**Figures 9B:**

**A: The percentage of success rate of young and old and oldest adults while performing cognitive game tasks during different physical loads. B: Response time of young, older and oldest adults while performing the cognitive tasks of the game during different physical loads. C: Execution time of young, older and oldest adults while performing the cognitive tasks of the game during different physical loads.**



## Chapter 5: Discussion

The present study examined the effects of aging on individual and dual task performances during standing balance, walking while head tracking and cognitive task performances in healthy young adults, community dwelling older and oldest adults. During standing on the sponge surface with eyes closed task, seventeen of the oldest participants had a fall. No significant age effect was observed during single task condition (i.e. while standing on fixed surface). A significant decrease in walking performance and cognitive task performance was observed due to the effect of aging. Significant dual task effects were seen in all the age groups while performing visuo spatial as well as cognitive game tasks.

### 5.1 Effects of age and dual task performance on standing balance

It is known that aging leads to reduction in tactile, vestibular and visual function and sensory processing relevant to balance control (Fitzpatrick et al., (1994); Peterka et al., (2002)). Balance is hard to achieve and maintain when there is a loss or distortion of signals from more than one of the sensory systems. A significant increase in body sway and loss of balance in older adults and people with a history of falls when there is distortion of two sensory inputs such as tactile input from the support surface and visual input has been observed, Desai et al., (2010). The present study observed consistent results to the above studies as there was a large number of falls during the eyes closed, standing on the sponge condition in the oldest population.

Shumway-Cook and Horak developed the inexpensive and highly reliable CTSIB test as a measure of balance in 1996 using a dense sponge surface which allowed continuous perturbations in almost all directions. To distinguish older people with a high fall risk, a number of studies have used this test. The present study used a pressure mat on top of the compliant or fixed surface which can be used for community and small clinic settings instead of the expensive SOT test unit. It allowed the assessment of standing balance without any loss of COP distortion data, unlike in a heavy, expensive force plate due to placement of the sponge on top of the force plate, Betker A., (2011).

Desai et al., (2010) performed a study which examined standing balance of community dwelling older adults with a modified CTSIB (mCTSIB) test using a force pressure mat. They observed a significant increase in COP excursions between fallers and non fallers when participants performed standing with eyes closed tasks. The present study extends these results by comparing the age effect on standing balance by using the mCTSIB with the addition of visuo-spatial and cognitive tasks. It was observed that the standing with eyes closed task had a substantially higher number of fallers in the community dwelling oldest group in comparison with the young and older adults groups. The dual tasking also proved to be a significant cause of increased COP excursion leading to a high fall risk. The present study focused on observing COP excursions to assess and compare balance performances in young, older and oldest adults during standing with physical and concurrent cognitive tasks using a computer based assessment tool.

Here a significant increase in the COP excursions occurred when a concurrent task was added while standing on a sponge. This is likely caused by divided attention towards maintaining balance. The decline in ability of executive processing associated with mobility limitations can be an early marker of increased risk of falling, Gleason et al., (2009); Hong et al., (2010)

## 5.2 Effects of age and dual task performance on spatio-temporal gait parameters

Variability in spatial and temporal gait parameters is considered to provide an overview on the consistency of locomotor skills and stability during walking, Dingwell and Kang et al., (2007). Factors affecting the ability to walk include aging, dual tasking etc, (Chen et al., 2012; Sparrow et al., 2008; Bock et al., 2011; Yogev et al., 2012). Studies have shown that during over ground walking, gait speed is decreased. This is likely due to prioritization of walking or the physical task over the cognitive task which is a strategy to make the physical task less difficult by slowing down, Montero-Odasso et al., (2012), Jordan et al., (2007), Szturm et al., (2013).

In the present study, instead of over ground walking, participants walked on treadmill, compelling them to maintain a constant walking speed for the assessment of spatio temporal gait parameters. Thirty to 50 consecutive steps were used to assess spatial and temporal gait variability during single as well as dual tasking. If the speed is not maintained throughout the task, the actual effects of cognitive task performance on gait parameters cannot be assessed precisely.

In the present study, performance showed significant differences between the three age groups. A number of studies have associated an increase in gait variability with increased fall risk, (Verghese et al., 2006; 2009; Gleason et al., 2009). The individual walking performance results in the present study indicate that the community dwelling oldest population is at a higher risk of fall than the young and older adult population. The use of a treadmill along with concurrent cognitive and head tracking tasks helped us to evaluate the effect of dual tasks on spatial and temporal gait variability. The majority of DT studies to date evaluate over ground walking and demonstrate that gait speed decrease in DT as compared to the walk alone condition.

Most of the dual task walking studies assess gait variables but without quantifying cognitive performance. The effects of task conditions and age on the cognitive outcome measures need to be analyzed to quantify the cognitive performance , (Faulkner et al., 2007; Shumway- Cook et al., 2000; Beauchet et al., 2008; Herman et al., 2010). In the present study, all three age groups showed a decrease in most of the task performances while dual tasking as compared to the single task performances. Also, a significant effect of age was observed on spatial and temporal gait parameters while performing dual task walking with visuo-spatial as well as cognitive tasks. The decline in performance due to dual task and effect of age was evident for all the spatio-temporal gait variables.

We have used standardized computer tasks and quantified both, the head tracking task with a moving target and the cognitive tasks with distracters. Head tracking task performance has a high impact on smooth pursuit and vestibular ocular reflex; whereas the cognitive task has an impact on working memory, set thinking and executive functions. The results of the study prove that both of these tasks affect the gait performance significantly thus suggesting that the two tasks used in the present study are of similar magnitude but controlled by different cognitive processes.

### 5.3 Effect of increase in age and physical load on Head Tracking Performance

Head tracking ability is important in day to day life, for example when crossing a busy street. The present findings show contrasting results than the original hypothesis would have predicted, as a significant effect of age was observed in head tracking task performances of the oldest adults when compared to the other two groups. Thus there may be an effect of age on gaze performance when standing on a fixed surface. This can be explained as smooth pursuit eye movements are complex voluntary movements of the eye which are assimilated in frontal visual cortex and superior colliculus. The gaze stabilization during head movement using a smooth pursuit system is necessary for focusing on the moving target during the head tracking task while standing.

In the present study, there was a significant effect of walking on the head tracking performance as compared to standing in all three age groups. During dual task walking there is considerable passive head motion to compensate for performing head tracking task. The vestibulo-ocular reflex plays an important role in this by using the push pull mechanism to identify head movement and direction and stabilize gaze on the moving target during walking. A misinterpretation of the head movement and the direction will lead to problems with gait stabilization, postural stability and movement perception, Baloh R W., (1990).

Dual tasking causes a division of attention towards visuo-spatial and physical tasks. A number of studies performed previously to study dual tasking have used auditory-verbal memory cognitive tasks such as animal enumeration or number subtraction. These tasks lack a standard quantifiable outcome measure and do not involve the visuo-motor system. Standing balance, as well as walking while maintaining equilibrium requires visuo-spatial processing of the surroundings with respect to the body and space. We hypothesized that age would have a significant effect on gaze performance during treadmill walking. The effect of walking on gaze performance of the three age groups showed a strong decline in the head tracking task performances as the age increased. This can be explained as there is more passive head motion during walking than standing and focusing on the target is more challenging while maintaining balance or physical load.

### 5.4 Effect of increase in age and physical load on cognitive task performances

A number of studies performed previously to study dual tasking have used auditory-verbal memory cognitive tasks like animal enumeration or number subtraction which lack a standard quantifiable outcome measures. In the present study visuo- spatial task were used which required a division of attention towards visuo- spatial and physical task. Motor control during standing balance as well as walking while maintaining stability requires visuo-spatial processing of one's surroundings with respect to body and space. Visuo–spatial performance is an important aspect of cognition that needs to be taken in to consideration when studying mobility decline, Murray et al., (2010); Bagurdes et al., (2008). This would be an important aspect of function to assess and quantify gaze control during walking where passive motion occurs.

The type and complexity of the cognitive tasks could provide a substantial difference in the added attention load during walking and thus on cognitive performance, Song et al., (2008). A number of studies in the past have used cognitive task performances to examine the dual task effect on standing and walking balance in young and old adults. It has been demonstrated previously that aging leads to a decline in cognitive performance which is a major factor in the risk of falls, Verghese et al., (2006), (2009), Bruce-Keller et al., (2011), McGough et al., (2011). In the present study we have examined cognitive task performances during standing as well as while walking in young, old and oldest adults. According to Hauffman et al., (2009), changes in the location of the object relative to the change in one's own position in space can share the same spatial processing resources. Thus, use of proper setting for the assessment of cognitive tasks performance is important when assessing the age effect

The present findings indicate that the individual cognitive task performance showed a significant decline in all the Success rate, Response time and Execution time during dual tasking and as the age increased. Cognitive game task also showed a significant age effect in the performance scores in the success rate and response time of the oldest population. It can be observed that the effect of aging on the cognitive performance was more easily evident in the oldest group than the other two groups.

A number of studies in the past that studied cognitive performance and fall risk due to cognitive decline and its effects in the dual task paradigm have used reaction time tasks, discrimination and decision making tasks, simple cognitive tasks such as counting backwards, or naming the days in a week etc. Since they use the data is recorded from a maximum of 4 to 5 steps, which means the participants are allowed to perform the cognitive task for less than 10 seconds. The outcome measures used are mainly based on Success rate and quality of the task is usually unquantifiable. This may be inadequate to assess the cognitive ability of the participant, Chu et al., (2012) suggested that tasks such as reaction time tasks or counting tasks have less effect on gait performances; hence use of a quantifiable attention demanding cognitive task is important when examining the effect of dual tasking. The task used was a simple visuo-spatial task. The task is computerized and standardized and also responses are quantifiable. In the present study we have combined all executive processing tasks and used them in assessing the effect of cognitive task on walking balance. We also examined the effect of aging on the performance of cognitive task as well as walking balance during dual tasking.

These cognitive tasks were assessed using not only the success rate but also response time and execution time in order to analyze the quality of the performance. Because a treadmill was also used participants were not allowed to compensate their walking speed resulting in precise evaluation of cognitive task performance while walking. There was a significant decrease in cognitive game task performance during dual tasking. The cognitive game task performances showed that the success rate and response time decreased significantly in all three age groups. This was most evident in the oldest population.

According to Huffman et al., (2009) head movements according to the falling target while maintaining ones location in the space during walking is performed by similar source of the sensory system. Thus, it is a challenging task to succeed in catching the target while maintaining a constant walking speed. The present study extends the scope of the above studies by using moving visual targets with conditions of standing on a fixed and sponge surface as well as treadmill walking, which results in increased body sway to give a better idea of effects of aging as well as dual tasking on the gaze performance without allowing the prioritization of the physical task over the spatial task.

Spatial memory required for activities of daily living is affected in normal aging, which is because of the decline of episodic and working memory, (Gras D et al., 2012, Kim MJ et al., 2013). The present study extends the scope of the above studies by using moving visual targets with conditions of standing on a fixed and sponge surface as well as treadmill walking, which results in increased body sway to give a better idea of effects of aging as well as dual tasking on the gaze performance without allowing the prioritization of the physical task over the spatial task.

## Chapter 6: Conclusion

To conclude, this study shows a vast decline in walking and standing balance and ability to divide attention during dual tasking between the age groups 55-70 years and 71- 85 years and compares both these age groups with a more normative, healthy, young (20-30 years old) population. Increase in age has a significant effect on dual task performances. The present study shows that the ability to divide attention without prioritization during dual tasking declines with age, which plays an important role when visio-spatial or cognitive tasks are performed with standing or walking. The effect of aging in the oldest group was significantly larger than the young and older population; on head tracking and cognitive task performances along with standing balance and spatial and temporal gait variables.

## Chapter 7: Clinical Significance

Using a treadmill in dual task studies allows us to study balance and mobility skill in further detail by using more steps and thus increasing the data per trial. The cognitive demands of gait control should be examined using a dual-task paradigm in which the interplay of standing/ walking and cognitive skills can be measured and analyzed precisely, Abernethy et al., (1988). Since most day to day tasks require divided attention the risk of falling is increased in the older population and people with motor and cognitive impairments,(Verghese et al., 2006; Hall et al., 2011). It is always preferable to assess frail individuals with fall risks before an incidence of mobility impairment occurs. Evaluation of clinically significant gait variables and cognitive skills are 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 in older adults. This will allow not only the differentiation of fallers from non fallers but also identification of older adults who are at a higher risk of falling.

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 treadmill rehabilitation platform to assess the dual task ability of young, older and oldest participants. Older adults can be trained for dual tasking using this platform, which can result in decreased risk of falling. A detailed analysis of cognitive and balance stability skills is allowed. The setup is minimal: a treadmill, a computer and screen and participants can train themselves for dual tasking in their community fitness centers or even without going out of their houses. Training older adults by using traditional exercise regimens can contribute to fatigue and loss of interest. Using an interactive gaming system such as this one will keep them motivated until their complete recovery.

**Limitations and Future Implications**

1. Future studies should be performed on patient populations to see the effect of any diagnosed cognitive deficit on balance and mobility. Also a co relational study should be designed to examine the correlations between cognitive deficits and mobility impairments where both cognitive functioning and mobility impairments are analyzed simultaneously. Also, a comparison of the physical and cognitive task performances of fallers and non fallers during the standing on the sponge with eyes closed condition should be performed to acquire a deeper understanding of the relationship between the risk of falls and dual task performance.
2. A training program for older adults to assess and treat cognitive as well as mobility impairments using the motivational computer game based treadmill rehabilitation platform should be conducted.
3. The results of the present study cannot be generalized as only physically fit participants were involved.
4. A Principle Component Analysis (PCA) should be performed on the variables derived in the present study to examine each variable and conclude which variable is mainly affected while dual tasking.

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