Aging effects on balance, gait and cognition during treadmill walking

By

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Abstract

Background

Limitations in mobility resulting from balance impairments contribute substantially to falls in older adults. Aging also has a detrimental effect on cognition which influences mobility and balance. A low cost treadmill rehabilitation platform (TRP) and a custom computer game that provided single and dual task challenges while standing and walking were used to evaluate standing balance, gait variables, visual tracking and cognition game performances in active young and older adults.

Objectives

The study objectives were, 1) to determine the differences in performance-based measures of standing balance, treadmill walking, visual tracking and executive cognitive function between young and older adults and 2) to examine the effect of age and dual tasks on performance-based measures of balance, gait, visual tracking and cognition in both groups.

Methods

Thirty active young adults (Mean age: 26.7± 2 years) and thirty older adults (Mean age 61.4± 4.4 years) performed visual tracking and cognitive game tasks on three different physical and cognitive loads on the TRP. The treadmill was instrumented with a force sense array (FSA) pressure mat to record the centre of foot pressure excursions. A motion sense air mouse (Gyration Elite) mounted on a custom made helmet was used to

interact with the on screen cursor of the computer screen to perform visual tracking and cognitive game tasks. Participants were also evaluated for balance using clinical tests.

Results

During single tasks, younger adults performed better than older adults in the AP direction while older adults demonstrated better balance in the ML direction. Single task walking did not demonstrate a difference between the two groups. During single task cognition, there was no difference during both cognitive games while young adults did better during the closed loop visual tracking task.

During the dual tasks, both groups demonstrated a dual task effect in balance, walking and cognitive tasks. Younger adults performed better than older adults in all the physical and cognitive load conditions.

Conclusion

The study findings provided evidence for discussion on the effects of single and dual tasking conditions in young and older adults. Understanding the effects of dual tasks has important clinical implications because older adults engage themselves in a wide variety of activities that require cognitive, mobility and balance skills simultaneously. Identifying the age at which there is a compromise on the above and providing appropriate interventions would be very useful to prevent falls.

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Dedication

This thesis work is dedicated to my son Andrew Samuel Srikesavan.

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Chapter 1: Introduction

One of the major health issues affecting older adults is falls. Mobility limitations, among other reasons are major contributors to falls. Mobility limitations can be the result of walking and balance impairments. Loss of independence, disability and death is associated with mobility limitations and disability brought about by balance and walking impairments in older adults [1, 2]. Several studies have linked balance and walking impairments to future falls and disability [3, 12, 13, and 14]. Identifying the age group of potential fallers and implementing appropriate fall prevention programs would prove to be very economical while preventing morbidity and mortality.

Another important aspect of aging is the effect of aging on cognition and the effect of cognition on mobility and balance function in older adults. Several authors have studied the link between cognition and mobility and its relationship to fall risk and falls [15, 16, and 17]. The ability of older adults to multitask has received more attention ever since mobility has been linked to cognition. Authors have been using several methods to mimic the dual tasking challenges that older adults face in the community. However some of the methods have several limitations. One of the major limitations of the methods used is that participants are made to walk only for a few steps while assessing mobility. During this period they are also asked to perform a cognitive task. However participants are able to prioritize the task they want to and the test doesn't become an ideal dual task. It is important that a system is developed that allows assessing participants safely while they walk and perform a cognitive task without being able to prioritize.

Chapter 2: Review of Literature

2.1 Balance assessment

Balance is controlled by the motor, sensory and cognitive systems. Changes in balance become evident due to the normal aging process that affects these systems. Several tools have been developed for the assessment of balance. Traditionally balance assessment was performed by single tests or batteries, which assessed performance of various tasks. The most common performance-based tests of balance control include the Timed Up and Go (TUG) test, the Berg Balance Scale (BBS), the Tinetti's Performance Oriented Assessment of Mobility (POAM) test and the Community Balance and Mobility Scale (CBM). These tests consist of single or multiple tasks, which are quantified by the time taken to perform the task. There are also balance tests, which are done on equipment such as the Limits of Stability (LOS) test. A major limitation of these balance tests is that all of them are performed at the participants self-pace in a controlled and safe environment and on a fixed firm surface. The challenges in the form of surfaces and environment that these participants will have on their balance in the real world will be different and magnified. Others use questionnaires such as self-reported measures of balance such as the Activities Specific Balance Confidence Scale (ABC) and the Falls Efficacy International Scale (FES) and the FES-International version, where patients report their perceived balance or the confidence they have in their balance. These self-report measures have questions that range from simple household tasks like cleaning and meal preparation to complex outdoor tasks like walking on a slippery icy surface. A major limitation of these self-report measures is that the tool relies on the ability of the participant to imagine a task and make a decision as to if a task can be safely performed or not. There have been several studies conducted to study balance and its relation to falls and fall risk.

Muir et al, 2010 [3] performed a systematic review to evaluate the evidence linking balance impairments with risk of falls in community dwelling older adults. They reviewed 23 studies and conducted a random effects meta-analysis of 15 studies to generate a summary risk estimate and reported an overall fall risk with a risk ratio (RR) of 1.42 and an odds ratio (OR) of 1.98. The fall outcomes that were studied were any fall, recurrent falls, injurious falls and injurious falls with fractures. The most common period of follow up was for a period of one year. The authors do mention about the differences among studies in how they define falls. They concluded that balance impairments lead to a moderate increase in fall risk in community dwelling older adults. The authors also found significant associations for increased fall risk with the balance measurement scales of tandem stand, tandem walk, one leg stand, body sway and the performance oriented mobility assessment scale.

A total of nine balance measures have been used in the 23 studies that were reviewed some studies used multiple balance measures. It is known that different balance tests measure different components of balance. The performance on the TUG is going to be relatively easier than the performance on the single leg stand. Therefore combining results from studies that have used different tests and outcome measures can make the conclusion weak.

Muir et al, 2010 [3] conducted a secondary analysis of data on a study on 210 community dwelling older adults to find the contribution of clinical balance assessment on future fall risks. The authors hypothesized that clinical assessment of balance can identify future fall risks even after adjusting for other factors related to increased falls. The performance based balance tests used were the one leg stance with eyes open, tandem stance with eyes open, the limits of stability while standing. In addition, an observational gait assessment and self-administered questionnaire were performed. A total score was created with the outcomes of the balance tests. The results showed that the self-report question and the combined balance score showed a significant relative risk estimate with any fall or any injurious fall. In addition the one leg stance test and the limits of stability tests showed significant relative risk estimates with any fall. With these results the authors concluded that balance problems as identified by self-report and performance based methods are associated with an increased risk for falls.

There is questionable merit in creating a total balance score out of different balance tests that have different difficulty levels. The authors have also included an observational gait analysis and have not mentioned how they scored it and as such, it may lack reliability. The self-report of balance impairment was obtained from a single question that might confuse the participant as it deals with dizziness and balance impairment. The question asked was, “Sometimes people get dizzy or light-headed, and lose their balance. Other people report a loss of balance in their legs. Do you ever feel that you are losing your balance, other than when you feel dizzy or light headed? By that, we mean do you feel the problem is in your legs rather than the head”. How the scores of the different balance tests were combined was also not mentioned.

More advanced balance assessment systems such as the Sensory Organization Test (SOT) and the Clinical Test of Sensory Interaction and Balance (CTSIB) were developed which added the element of different sensory challenges. The SOT was initially developed by Nashner in 1971[4] to describe vestibular detection of body sway motion. This system was later named as the Equitest and commercialized by Peterka and Black in 1990 [5]. This laboratory model allowed the elimination of the sensory cues that help orientation while retaining the vestibular sensors. Sensory cues that are produced by the movement of the ankle joint and muscle length changes were eliminated by using a special platform, which allowed sway motions of the body while maintaining a fixed ankle angle. The platform could make the participant experience a free fall sway either in front or the back. Participants were asked to stand on the platform and the body sway was induced by using platform displacements. The system also consists of a visual sway that can also move along with the platform. The test is conducted under 6 sensory conditions with each condition becoming more complex than the earlier. In the first sensory condition the participant stands on the platform with the eyes open. Both the support surface and the visual surround are not moved and the participant can rely on the visual, vestibular and somatosensory inputs to maintain their balance. During the second sensory condition the participant stands still on the support surface with eyes closed. Closing the eyes eliminates the visual inputs. The third sensory condition requires the participant to stand on the support surface and the visual surround moves along with the body sway. Here the visual system signals that the body is not moving, while in reality the body moves and if the participant relies solely on the visual system they would fall. In the fourth sensory condition the platform on which the participants stand also moves as the participants move forward and backward. In this situation the information conveyed by the somatosensory system will be inaccurate and if the participant does not rely on the visual and vestibular systems they will fall. The fifth sensory condition is similar to the fourth but participants are asked to close their eyes. This denies them inputs from their visual system and they have to rely solely on their vestibular system. In the sixth sensory condition the support surface and the visual surround move with the body sway. The inputs from both the visual system and the somatosensory system would be misguiding and the participant has to rely on the vestibular system. The maximum peak to peak center of pressure of the foot quantifies performance on the SOT.

The SOT is an expensive system and hence researchers made efforts to develop systems that could measure similar features at a lower cost. In 1986 Shumway-Cook and Horak [6] developed a system called the Clinical Test of Sensory Interaction and Balance (CTSIB). They replaced the platform with a foam pad, which allowed sway in all directions compared to the unidirectional sway produced by the SOT. Another advantage of the CTSIB is that participants can be made to perform upper limb and trunk movements while standing on the foam. The initial version of the test was conducted under four conditions; with eyes open and closed on a firm surface and eyes open and closed on a foam surface. Participants were made to perform a maximum of three, 30-second trials and the trials were stopped if they deviated from the initial crossed arm position, or open the eyes in an eyes closed trial, or move the feet/require manual assistance to prevent loss of balance. Body sway is quantified as a numerical rank (1=

minimal sway, 2= mild sway, 3=moderate sway, 4=fall) using a grid to record body displacement and the time that the participant stood in each attempt. The CTSIB has been found to have excellent (r=0.99) test-retest reliability (7) and moderate (r=0.79 to 0.84) correlations with the SOT (8).

Abrahamov 2008 [9] studied standing balance on both fixed and sponge surface on 81 healthy participants between 20-82 years of age. Participants were asked to stand still under 4 conditions; while standing on a firm surface with eyes open and eyes closed and stand on a 10 inch thick foam surface with eyes open and eyes closed. Participants included three age groups as juniors (20-40 years), middle-aged (40-60 years) and seniors (60-82 years). The standing balance test involved four conditions during static standing. The root mean square, line integral and total area were quantified by the Center of Pressure (CoP) path in both antero-posterior (AP) and medio-lateral (ML) directions. They were analyzed for within group differences in the eyes open and closed and firm surface and foam surface conditions. They also analyzed differences between the three groups. The results revealed that seniors showed the largest increase in CoP excursion parameters in all four conditions and the largest body sway was seen when participants were on the foam surface with eyes closed. There were significant differences between juniors and seniors and middle aged and seniors in most parameters and conditions.

It is apparent from this study that as balance is challenged by making participants stand on a difficult surface or by eliminating vision, there appears a clear difference in the performance with increasing age. Balance skill under altered sensory conditions in older adults deteriorates with age. It is important to note that changes in balance start to appear in middle age. This has clinical significance as simple assessments can be done at this stage and it is likely that preventive measures can be implemented anticipating the balance problems that are expected due to old age. This work was extended by Desai et al in 2010 [10], who studied dynamic standing balance on 72 community dwelling older adults aged 65 years and above, while they performed 6 different tasks on a fixed normal surface and a sponge surface. A force sense array (FSA) pressure sensing mat was placed over a wooden board that was placed over a sponge. This arrangement provided equal distribution of forces. Both AP and ML CoP were calculated from the recorded CoP displacement data. It is important to note that a composite score was computed for both fixed surface and sponge surface. One of the main findings the Dynamic Balance Assessment (DBA) is that the composite score only on the "sponge" had a predictive value while the CTSIB score of composite score on fixed surface did not. CoP excursion variables were categorized into quartiles with lesser scores indicating better performance. Composite scores for the summed performance scores on the fixed and sponge surface were then determined. In addition several clinical balance tests were also conducted; the TUG, the Berg Balance Scale (BBS), the Six Minute Walk Test (6-MWT) and the gait speed test. The 6 DBA tasks were performed on both firm and sponge surfaces. The tasks were quiet standing with eyes open and closed, standing and performing head rotations, standing and performing a rhythmic arm lifting and lowering task, standing while performing rhythmic trunk rotations and standing and performing trunk bending. The objectives of the study were to identify if CoP measurements on the DBA system would be able to distinguish fallers from non-fallers and to find the correlation between the CoP measures on the DBA and other balance measures. The results of the study revealed that there was an increase of loss of balance (LoB) frequency when the tasks were performed on sponge surface compared to firm surface. The peak excursions and the Sway Path Length (SPL) were approximately two to three times more on the sponge surface when compared with the firm surface. The DBA composite scores were able to distinguish between fallers and non-fallers only on the sponge surface. Only the TUG showed a significant difference between fallers and non-fallers. This study reveals significant decreases in balance performance when the support surface is distorted and when performing activities involving whole trunk movements. This has clinical significance as older adults have to perform various activities while they are standing and they also have to negotiate several types of surfaces during their activities of daily living (ADL). Balance assessment and therapy measures should take this fact into consideration as clinical balance measures alone may not be able to identify balance issues in older adults. The low correlation between the functional balance tests and the DBA suggests that the DBA is able to pick up more subtle changes and the functional balance tests that are performed under a controlled environment may not always be able to pick up balance impairments as effectively as the DBA.

The above studies provide information that as the surfaces on which participants perform tasks become complex and unpredictable then balance performance is challenged and loss of balance often results in older aged adults. Similar to other studies, performing balance tests with the eyes closed also substantially increases body sway and fall occurrence. This indicates that sensory inputs play an important role in balance performance and elimination or reduction in spatial sensory information is likely to affect balance negatively. Another important inference from the above studies is the effect of age on balance impairments. There is a strong relationship with increasing age and reduction in balance performances. This becomes more evident as the surfaces and tasks become more complex and demanding. There is also a need for low cost balance assessment methods and systems like the DBA which can be set up in a limited space and can detect balance impairments in a similar if not better way than costly systems such the SOT and CTSIB.

2.2 Aging, mobility and dual tasking

Along with a single task of walking that is affected due to aging, dual-tasks are also affected. Dual-tasks can be defined as performing a balance or mobility task while concurrently responding to a cognitive task or challenge. It is been shown that when resource sharing or capacity sharing occurs, one or both of the tasks are affected. Capacity sharing is an accepted theoretical model that explains how we are able to perform dual tasks for a time and when one of the tasks gets performance that is more difficult suffers [11]. This fact is important in the light of falls and the risk of falls in older adults. If older adults are not able to maintain their balance and mobility while performing, dual tasks will increase their risk of falls. This is a challenge, as older adults are required to engage themselves in a wide variety of dual tasks as part of their activities of daily living, employment and leisure activities. Quantifying difficulties encountered in dual tasks can also serve as an early sign to predict future falls and mobility disability. Dual task abilities in older adults have been examined with several study designs.

2.3 Incidence of gait and cognition problems in older adults

Approximately one third of all community dwelling adults over the age 65 sustain falls each year. Two studies [12, 13] followed a group of 379 adults for 54 months to determine if gait variability was able to independently predict incident mobility disability (self-report of the ability to walk half a mile). Gait characteristics were assessed on a 4-meter GaitMat II (EQ Inc, Pennsylvania) walkway. Participants were asked to walk across the mat twice at their self-selected speed (10-12 steps). The authors looked at gait speed, step length, step width and stance time. The standard deviations of these parameters were used as the measure of variability. After adjusting for gait speed, gender, race, prescriptive medications etc., only greater stance time variability (0.5 SD) was related to a higher incidence of mobility disability (13%). This is an important study, as many studies look at gait speed alone while this study has looked at variability. This study has also followed up on participants for 54 months which is a long duration and provides valuable information on future falls over a long period.

Verghese et al, 2009 [14] followed a study sample of 597 older adults aged 70 years and above for 20 months with an objective to determine whether and to what extent gait speed and other gait variables are independently associated with the risk of falls. Participants were asked to walk on a GaitRite ® carpet for two trials. The variables assessed were gait speed, cadence, stride length, swing, double support, stride length and swing time variability. Falls were monitored by telephone calls every two to three months. Relative risks (RR) were calculated to explain the association between the gait variables and any fall over the 20 month period. Relative risk values that are > 1 indicate a strong positive association. The results showed that a slower gait speed (< than the mean gait speed of 92.8 ± 24.1 m/s) was significantly associated with an increased risk of falls (RR 1.069). Other gait variables that significantly predicted fall risk were swing time, with a relative risk of 1.406, double support time (RR 1.165), swing time variability (RR 1.007) and stride length variability RR (1.076). This study demonstrated that some quantitative gait markers have value in independently predicting falls in older adults and decreased performances on these gait variables are associated with an increased risk of falls.

Herman et al, 2010 [15] prospectively studied 262 community dwelling older adults for 2 years to determine if executive function predicted falls. Falls were monitored by using a monthly log. Cognitive function was assessed using a computer based neuropsychological test battery (Mind streams). Executive function was assessed by the Go-No-Go test and Stroop interference test. The test battery generated a composite score for the all the tests on an Intelligence Quotient like scale while also providing individual cognitive domain scores. Dual task gait was assessed by asking the participants to walk for 2 minutes on a 25 meter hallway while subtracting serial threes from a predefined three digit number. Participants wore force sensitive insoles that quantified gait speed and swing time variability. The following results were observed. The mean and standard deviations of executive function were significantly worse in those who reported a fall (97.9 ± 10.7) during a two year period than those who did not report new falls (100.6± 10.7=6). A student t test also showed that gait variability, as measured by swing time variability during the dual task was worse in fallers (Mean and Standard deviation 3.2 ± 1.8%) when compared to non-fallers (Mean and Standard deviation 2.7 ± 1.1%). The results also revealed that the participants who came under the worst quartile of executive function scores were three times more likely to fall than those with better executive function scores. Odds ratios (OR) were calculated to find the strengths of associations. An OR that is > than 1 indicates a strong positive association. Executive function index (OR= 3.2) and gait variability under dual task conditions (OR= 1.29) significantly predicted multiple falls status in a univariate regression model. Participants who scored lowest (more than 1 SD than the mean of age and education expected norms) in the EF index were 3.2 times more likely to fall than those who scored higher.

2.4 Relationship between physical and cognitive difficulties and falls and fall risk

There have been several studies that have examined the association between cognitive abilities and physical performance in older adults. It was not initially thought that gait was a cognitive process. However, there has been increasing evidence that gait and its parameters are related to cognition.

Beauchet et al, 2009 [16] performed a systematic review on studies that tested the association between falls and the changes in gait while dual tasking in older adults. A total of 15 studies were reviewed. Fall occurrence was significant and showed strong associations with dual tasking abilities in 11 studies (OR 5.3). The review concluded that changes in performance while dual tasking was significantly associated with an increased risk of falling in older adults. However these significant associations were observed in studies on older adults who were institutionalized and those who were geriatric inpatients. This makes it impossible to generalize the results to all older adults as these participants would have had different morbidities to be institutionalized and/or inpatients.

Hsu et al, 2012 [17] conducted a systematic review on 25 studies that examined the relationship between cognitive processes and physical performance in older adults aged 60 years and older. There were 12 studies that reported significant associations between executive function and fall risk. Results were presented in terms of odds ratios and correlations. In the studies that reported odds ratios, the significant odds ratios ranged from 3.02 to 53.0, which predicted very strong associations. In the studies that reported correlations, values ranged between 0.23 and 0.37 were significant but weak.

Faulkner, 2007 [18] studied 377 participants to find if poor multitasking abilities were associated with a history of recurrent falls. Participants were asked to sit or walk and perform a cognitive task at the same time. Three different cognitive test conditions (no reaction time, push button reaction time and visual spatial decision reaction time) were performed under three different postural conditions (sitting, walking straight and a turn walk). The “single task” or control condition was where walking or reaction times were assessed separately. Dual tasks included walking straight or walking and turning, combined with reaction time to a simple audio tone or a more complex visual spatial task. For the visual spatial decision reaction time, participants were asked to look at a clock and say out aloud if the time was the same or different from the time of the day prompts they were listening to on headphones. Reaction time of the response reporting the observed time on the clock and the reported time was recorded. Walking tasks included walking straight for 20 meters in a corridor or a 20 meter walk that included a turn at 10 meters. Participants were asked if they had a fall in the last 12 months. Recurrent falls were defined as having two or more falls in 12 months. Reactions times, walking times and falls history were compared. The results showed an association between poor walking time response and higher odds of recurrent fall history on the visual spatial straight walk (OR=1.34) and turn walk (OR=1.42). The results also revealed that during a visual spatial task, an increased walking time response was significantly associated with higher odds of recurrent falls history on the straight walk (34%) and turn walk (42%). The results suggested that older adults who walk slowly when challenged with visuospatial tasks are at a risk for multiple falls. This result has clinical significance because if a simple dual task gait test can provide information on future fall risks the same can be done during routine assessments in older adults. It also provides information to implement fall prevention measures to reduce the risk.

McGough et al, 2011[19] studied 201 cognitively impaired older adults to find the association between physical performance (Gait speed and TUG) and executive function (Trail making test-B and Stroop color word test). Gait speed was assessed by the time taken by the participants to walk a distance of 8 feet in a hallway. The participants were also timed on their performance in the TUG. The authors reported strong associations between the TUG and the TMT-B (r^2=0.8) and moderate association with the Stroop color word test (r^2=0.6). The authors have also reported moderate associations between gait speed and the TMT-B (r^2=0.7) and the Stroop color word test (r^2=0.5).

Buchman et al, 2011 [20] conducted a study with an objective to examine the association between cognitive function and the risk of mobility impairments and also the rate of declining mobility on older adults. There were 18 cognitive tests used which included episodic memory, semantic memory, working memory tests, perceptual speed and visuospatial ability. Mobility function was assessed by three tests; walking 8 feet, turning around 360 degrees and single leg standing for 10 seconds. The time and the number of steps taken to complete the 8 feet walk and 360 degree turn were measured. A score of 0 to 5 was given for the performance on the single leg standing tests, with 0 being unable to perform and 5 being able to stand for 10 seconds. All the six measures were converted to a composite mobility measure. Having a gait speed of ≤ 0.55 m/s was described to have impaired mobility. The results showed that declining global cognition and the different cognitive abilities were weakly associated with declining mobility (r-values ranging from 0.25 to 0.34).

Beauchet et al, 2012 [21] studied 78 healthy older adults to find the association between gait variability and executive sub domains. Stride time variability was assessed by the SMTEC system (Foot switches) while participants walked on a 10 meter walkway in a 20 meter corridor. Participants were divided into three tertiles (lowest, intermediate and highest) based on their stride time variability values. The cognitive tests that were used were the forward and backward digit spans test, the Trail making test A and B and the Stroop color word test. The results revealed that the highest tertile of stride time variability was associated with lower performance on the digit span test (OR=0.78). Though the authors have used the Trail making and Stroop color word tests, they have not discussed why they didn't find any association for these tests with stride time variability even though McGough et al, (2011) [19] has shown that these two tests are associated with gait changes.

The above studies reveal that there is a relationship between cognitive abilities and physical performance or dual tasking in older adults. They have also shown that these abilities are able to predict falls. However, causality cannot be determined through association studies. Several studies have assessed the effect of dual tasks on gait and cognition in older adults.

A systematic review conducted by Hsu et al in 2012 [17] looking at the relationship between cognitive processes and physical performance in adults aged 60 years and older, found that in 13/25 studies, dual task performance was a strong predictor of falls and fall risk. Al-Yahya et al, 2011[22] performed a systematic review and meta-analysis of 66 experimental studies that measured gait performance with and without performing concurrent cognitive tasks in both younger and older adults. The cognitive tasks of the different studies were categorized into five cognitive domains which included tasks related to reaction time, discrimination and decisions making, mental tracking, working memory and verbal fluency. The gait variables of interest in the studies were speed, cadence, stride length, step width, stride time and stride variability. Interference in the gait variable with the cognitive tasks was termed cognitive motor interference (CMI). Meta-regression showed that only, mental tracking tasks reduced gait speed in the older adults while the other cognitive tasks did not significantly influence gait performance. None of the gait variables were affected in the younger participants.

Huxhold et al, 2006 [23] compared the dual task performance of 20 young adults and 19 older adults to study postural control and cognitive function. A force platform was used to assess the center of foot pressure (CoP). The displacement of the CoP or body sway, quantified postural control. The cognitive tests that were used were the choice-reaction time task (Out of random series of 22 digits between 1 and 9, participants were supposed to select the target digits between 1 and 3), digit 2-back working memory task (A series of 22 digits ranging between 1 and 9 were presented and participants had to indicate if a presented digit was the same as the one that was presented two steps back in the sequence), and spatial 2-back working memory task (A series of 22 dots appeared on boxes in a 3 by 3grid and participants were asked to identify if the location of a dot was the same as the one two steps backwards). Reaction time and response accuracy were the dependent variables for the cognitive tasks. The dual task tests were performed with the participant standing on the force platform and performing one of the cognitive tests. The results showed that in both single and dual task conditions older adults showed higher magnitudes of CoP excursion i.e. more body sway, poorer postural control, and lower cognitive performance than younger adults.

Srygley et al, 2009 [24] compared 276 healthy older adults with 52 healthy young adults to determine the effects of walking on the performance of three cognitive tasks. The cognitive tasks used were phoneme monitoring (participants listened to a story on earphones and counted the number of times a pre-specified word appeared) and serial 3 and serial 7 subtractions (participants subtracted 3 or 7 from a predetermined number). Performance was quantified by the number of mistakes, total number of subtractions, the phonemes counted and the content mistakes. Participants performed the cognitive tasks in both sitting and walking with force sensitive insoles along a 25-meter long and 2-meter wide corridor. There was no difference in the cognitive performance of young adults between sitting and walking except in the serial 7s deduction task during walking. But the older adults showed significant differences in the cognitive performance between sitting and walking. During walking, there was a decrease in the performance of older adults in the cognitive tests of serial 3 and 7 subtractions and phoneme counting.

Al-Yahya et al, 2009 [25] studied gait performance in 13 healthy young adults. The walking task was performed on a treadmill. Participants walked three trials with different inclinations of 0, -5 and -10 %. A dual task element was introduced by asking the participants to count backwards by sevens from a random number between 291 and 299. Spatio-temporal gait measures, pelvic angular excursion and sacral center of mass motion (CoM) were acquired while walking and while walking and performing the cognitive task. As compared to single task walking, walking and performing a cognitive task significantly increased step width and medio-lateral CoM displacements irrespective of the different inclination levels. A major limitation of the study was the small sample size of 13.

Ijmer et al 2012 [26] studied the relationship between executive function tasks and gait variability and stability during single and dual task situations in three groups of participants aged 75 to 85. The three groups included older adults with dementia (n=15, mean age=81.7), age matched older adults (n=14, mean age=76.9) and another group of younger elderly (n=12, mean age= 64.3). Gait was assessed by asking the participants to walk for 3 minutes at a self-selected pace on a 10 meter course. Gait speed and stride time (mean and coefficient of variation) were assessed for the participants during each task. Walking stability was assessed from recordings of trunk linear acceleration using the Harmonic ratio, sample entropy and maximal lyapunov exponent. The cognitive tasks used were category and letter fluency (naming animals, professions and words starting with the letters D,A and T), the Stroop color word test (psychomotor speed, response inhibition and cognitive flexibility), the digit span forwards and backwards tests (assess levels of attention, concentration and working memory) and the Trail making tests A and

B (planning and attention). Each group performed all of the cognitive tasks in sitting (single task). The dual task condition was walking on the 10 meter walking course while performing only the letter fluency task again with the letters R, G and P. There were significant differences in walking speed and stride time between the three groups during single and dual task walking. There was also a significant difference in the cognitive performance between the three groups during single task and dual task conditions. Patients with dementia performed significantly worse in the dual tasks than the older and younger controls. During dual task walking, older participants were significantly different from young adults in the root mean square, sample entropy and harmonic ratio of Antero-posterior trunk and medio-lateral trunk accelerations. Other studies have also demonstrated that older adults had trouble performing dual task activities; however these studies used different methodologies to assess cognitive function and physical function [16, 21, 27, and 28].

Chapter 3: Study Rationale, Objectives and Hypotheses

3.1 Study rationale

A limitation of most of the reviewed studies is that they have used the GaitRite system to assess gait parameters. When using the Gaitrite system, participants will only be able to walk a maximum of 4 steps and this is a quite limited sample number especially when computing gait variability. Natural gait involves a process that requires a few steps for the acceleration and deceleration. Thus the actual number of steps of the natural gait of the participant that will be observed is very limited. Some studies have tried to overcome this by making the participants walk several trials on the GaitRite system in both directions. However, in this situation participants have to stop in order to turn and they would naturally slow down when they see the end of the carpet realizing that they have to turn. Another disadvantage is that the participant can always prioritize the task that they wish to complete while compromising the other task. While walking on the GaitRite system participants can always reduce their speed and concentrate more on the cognitive task they are asked to perform. The Treadmill based Rehabilitation Platform (TRP) overcomes both these disadvantages by making the participant walk on the treadmill which maintains a constant speed. The participant can also be made to walk any number of steps while performing the cognitive task. A previous study (55) by Sakhalkar et al, 2013 found moderate to high test retest reliability for the performance measures on the TRP. They also looked at the performance of standing balance, treadmill walking, visual tracking and targeted executive function of thirty older adults (61.4± 4.4 years) on the TRP. It is important to examine how young adults perform on the TRP and compare the results with older adults. In this way we will be able to determine any difference in the performances among age groups which would allow the possible identification of an early indicator of poor performance.

3.2 Study objectives

1) To determine if there is a difference in performance-based measures of standing balance, treadmill walking, visual tracking and targeted executive function between healthy active young adults and older adults.
2) To determine if there is an effect of dual tasks (combining balance tasks or treadmill walking with visual tracking and cognitive tasks) on balance, gait, gaze and cognitive performance in young and old adults.
3) To examine the effect of age on dual-task performance levels for balance, gait, gaze control and executive cognitive function.

3.3 Study hypotheses

1) Performance-based measures of standing balance (fixed and sponge support surfaces), treadmill walking, visual tracking and targeted executive function will not be different between healthy and active young adults and healthy older adults during single tasks.
2) There will be a significant reduction in standing balance, mobility, cognition and visual tracking performance of healthy and active young adults and older adults during dual tasks when compared to single tasks.

3) During dual task conditions there will be an age effect in standing balance, mobility, cognition and visual tracking performance.

Chapter 4: Methodology

4.1Ethics approval

The study was approved by the Human Research Ethics Board of the University of Manitoba (Bannatyne Campus) vide approval letter number H2012: 084.

4.2 Participants

Thirty active young adults aged between 20 and 30 years (26.7± 2) were recruited from local gyms and games/sports teams and clubs. The data obtained from the young adults was compared with the data obtained from healthy older adults (61.4± 4.4) that was collected in the same laboratory by Sakhalkar (2013) [55]. The methods and instruments used for both groups were identical.

4.3 Inclusion criteria

1) Participants should be able to speak and understand English
2) Participants should be active and play games/sports regularly

3) Participants should self report that they are engaged in at least moderate exercise according to the International Physical Activity Questionnaire

4.4 Exclusion Criteria

1) Participants who have any musculo-skeletal disorders that would prevent them from performing the assessment tests
2) Participants who have had any recent medical illness

4.5 Recruitment

1) Recruitment posters were put up in the reception and exercise areas at the Reh-Fit center, and local gyms and games/sports teams and clubs including those of the University of Manitoba.

2) Those who were interested in participating in the study contacted the investigators, whose contact details were on the poster for further explanation about the study.

4.6 Study setting

The data collection sessions were conducted at the Reh-Fit Center in Winnipeg where the TRP was located.

4.7 Data collection sessions

Each volunteer participant was seen on one occasion. The session took approximately 60 minutes and involved the following:

1) Obtaining consent and background information
2) Visual tracking performance using the custom computer tracking software
3) Two cognitive function tasks using our custom game.
4) The treadmill game protocol testing (see below for description of balance and walking tasks)
5) Balance and gait performance measures from control and dual-tasks conditions
6) Clinical balance tests
7) Answering a take home questionnaire

4.8 Data collection instrumentation and recording of data

4.8.1 Force Sense Array (FSA) pressure mapping mat fixed on a treadmill

Figure 1 shows the treadmill with FSA mat. An automated treadmill (SportsArt Fitness Ltd, Taiwan) and handrails were used for the study. An FSA mat (Vista Medical Ltd, Winnipeg, Canada) embedded in thick Teflon was placed under the treadmill belt. This mat recorded the CoP excursions while walking on the treadmill. The FSA pressure mat included 512 sensors and each sensor covered an area of 2.8 squared centimeters. Spatial and temporal gait parameters were extracted from the foot contact and CoP excursions during walking.

Figure 1: Force Sense Array mat placed under the walking belt of treadmill

4.8.2 FSA mat used for standing

Figure 2 shows the FSA mat that was used to collect data during standing tasks. This mat recorded the CoP excursions while the participant stood on a fixed surface, a compliant sponge surface and while they performed cognitive tasks on these surfaces. The mat consisted of 256 sensors and each covered an area of 2.8 squared centimeters.

Figure 2: FSA mat used to collect CoP Excursions during standing task

4.8.3 Gyration Elite motion sense mouse

Figure 3 shows the air mouse (Gyration Elite) that was mounted on a custom made helmet. This system was used to interact with the on screen cursor of the computer screen to perform cognitive games and the visual tracking task. The air mouse mounted on the helmet moved the cursor through head rotation while allowing the participants to keep their hands free. Inertial sensors are used by the air mouse to derive angular displacement signals.

Figure 3: Gyration Elite motion sense mouse

4.8.4 Custom computer game

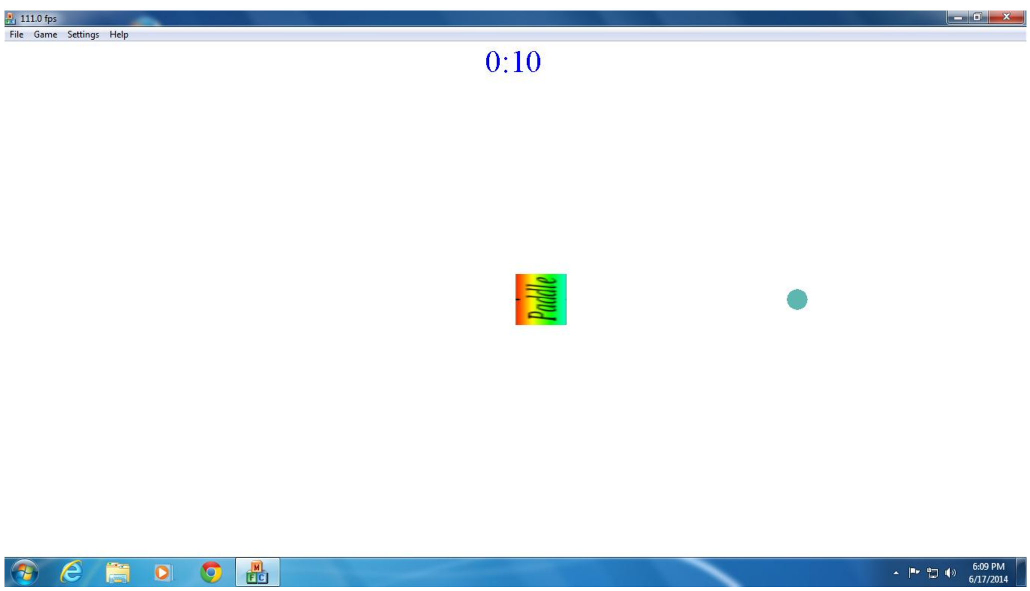
An interactive computer based game application was custom made and this enabled the recording of the coordinates of the head movements made by participants. The game consisted of two modes. One mode recorded the ability to track a target cursor on the screen and the other allowed catching targets falling vertically from the top of the screen.

Visual tracking mode of the interactive game application: This required a horizontal sinusoid tracking movement of an onscreen cursor. The cursor was represented by a brightly coloured circle. The frequency and amplitude of the sinusoidal movements were predefined at 0.7 and 0.4 respectively. One task was performed using this application.

Closed loop smooth pursuit tracking task with respect to head rotation

Figure 4 shows a picture of the closed loop visual tracking task as it appears on the screen. The picture illustrates the target cursor, which is the orange solid circle and the paddle which represents the mouse cursor that is moved by the participants head rotation movement. The objective of the task is to try and move the paddle in concert with the solid circular target and try to overlap. This task requires the participant to foveate to determine the amount of overlap between the target and the cursor. Participants performed this task for 45 seconds each while standing on a fixed surface, standing on a sponge surface and while walking on the treadmill.

Figure 4: Closed loop visual tracking task



Cognitive game mode of the Interactive game application

A classic paddle-based game was customized to make an episodic random game design. This game was designed to evaluate executive functions such as visual spatial processing, cognitive interference and processing speed. The game required the participants to move a paddle that was controlled by the air mouse on the participant's helmet. The participant was required to move the paddle to the left or right and catch the targets that fell from the top of the screen at random spots on the screen every two seconds. The number of targets hit, the time taken to reach the target from its initial position and the time from the appearance of the target to the start of the paddle movement were recorded. Two levels of complexity were performed, simple and moderate.

Figure 5 show the simple cognitive task where the targets fell at random points of the screen and the participant used the head mounted air mouse to move the paddle to try and catch the targets. This task was performed for 60 seconds each while standing on a fixed surface, standing on a sponge surface and while walking on the treadmill.

Figure 5: Simple Cognitive Game Task

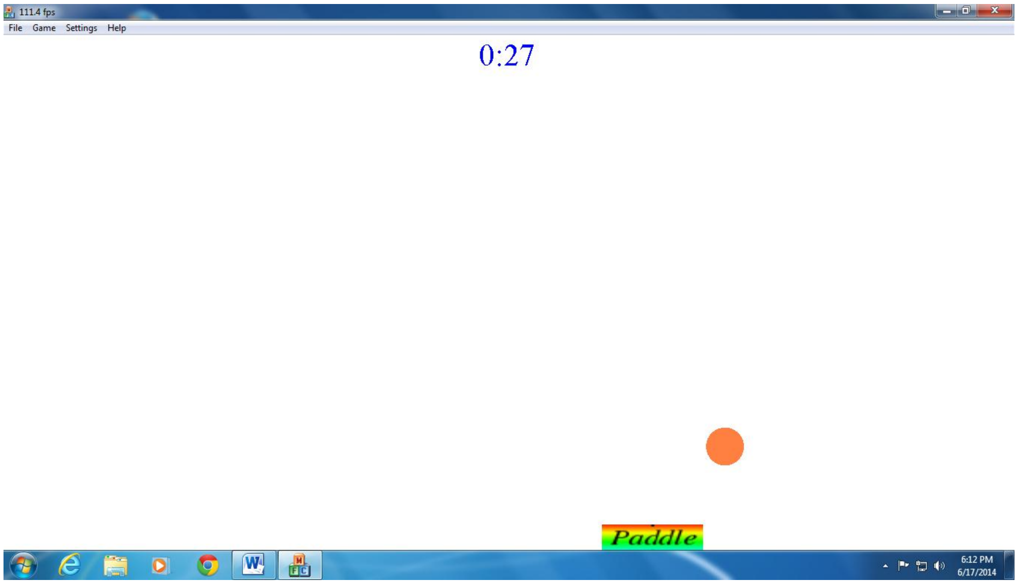
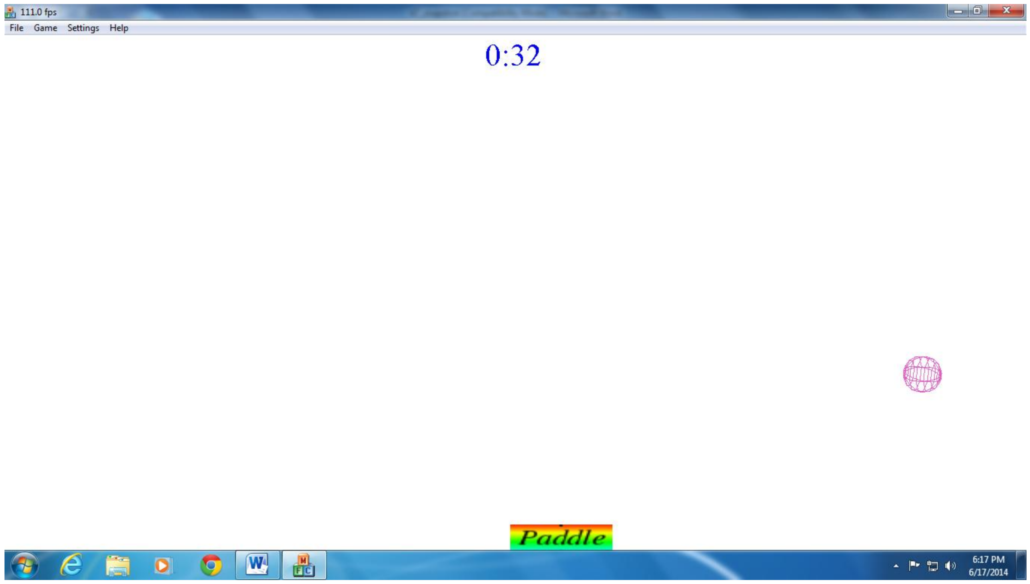


Figure 6 shows the moderate cognitive task where the targets fell at random points of the screen and the participant uses the head mounted air mouse mounted on their head to move the paddle to try and catch the targets. The complexity of the task was increased by distractors falling down from the top of the screen at random spots. The aim here was to avoid catching the distractors, while continuing to catch the solid circles. The distractors appeared as a sphere on the screen and were clearly distinguishable from the targets. If the participant caught a distracter, the game paddle would be destroyed. This task was performed for 90 seconds each while standing on a fixed surface, standing on a sponge surface and while walking on the treadmill.

Figure 6: Moderate Cognitive Game Task



4.9 Outcome measures and procedures

4.9.1 Dual-task

The visual tracking task and the cognitive game tasks were performed under the following conditions of increasing physical demands

1) Standing on a fixed floor surface (Control)
2) Standing on a compliant sponge pad (increased balance cost and to emulate outdoor terrains)
3) While walking on the treadmill at a walking speed of 0.9 m/s and at 1.2 m/s.

We used an inexpensive, commercial visual tracking computer mouse (Gyration In-Air mouse). This motion mouse translates head rotation (left-right /or up-down) into an onscreen cursor motion identical to a standard computer mouse. The participant is asked to wear a light-weight head band, which includes the wireless mouse. Thus participants can play the computer cognitive games and perform the computer visual tracking tasks - hands free, while balancing and walking. The participants also wore three motion monitors (NextGen) at the ankle, waist and chest. These motion monitors serve as accelerometers and magnetometers and detect three dimensional movements of the leg, trunk and waist. Antero-posterior, medio-lateral and vertical movements are detected by the motion monitors. The total time to complete these tasks (with rest periods) is around 20 minutes.

Visual tracking task using our custom game

The visual tracking task takes 45 seconds to complete. It is a closed loop tracking task. There is a paddle on the screen, which can be moved horizontally towards the left and right by moving the visual tracking computer mouse. There is also another solid circle that will be moving horizontally on the screen to the left and the right. The speed of movement of the solid circle is programmed into the computer. The task of the participant is to try and overlap the paddle onto the solid circle. During the closed loop task the paddle remains on the screen for the entire 45 seconds.

Cognitive function tasks using our custom game

Different features of the clients' game movements and choices provide a basis for objective quantification of select executive functions. Two cognitive games are played for 60 to 120 seconds. The first game involves a paddle that moves to the left and right on the screen at the bottom. The participant controls the movement of this paddle by moving the head to the left and right and the visual tracking computer mouse is synced to the paddle. There are solid circles that drop from the top of the screen at a predetermined speed but at random times. The objective of the game is to move the paddle and catch the solid circles before they touch the bottom of the screen. The second game is similar to the first game but an extra challenge is given by adding distracters to the game. In addition to the solid circles that fall from the top, there are three dimensional shapes that appear like a snow flake falling from the top. These serve as distracters and the participant is requested to avoid these distracters while continuing to catch the solid circles. If they catch a distracter the paddle disappears for 2 seconds as a penalty.

Balance and gait performance measures from control and dual-tasks conditions

The support surface (sponge pad and the treadmill) are instrumented with a pressure mat which records: (a) Centre of foot pressure data used to compute balance performance measures in standing conditions and during treadmill walking. (b) Time and location of each step. From this data we can compute a variety of gait variables e.g. step length/width, stance duration and double-support time. The outcome variables that are assessed from the FSA mat on both fixed and sponge surface are the root mean square (RMS), peak to peak and path length (Mean trial velocity).

4.9.2 Clinical balance tests

Participants also performed the following commonly used balance tests. Participants wore the motion monitors during the clinical balance tests.

1) Single leg standing for 15 seconds with eyes open and closed

This test is performed on a fixed surface and the participant is asked to stand on one leg at a time on the FSA mat. Both right and left legs are tested.

2) 15 feet forward tandem walk.

Two trials were performed. The first trial while looking at the feet and the second trial while looking forward. The 15 feet tandem forward walking test was graded by the investigator by visual observation into 5 grades; Excellent = Grade 5, Good = Grade 4, Fair = Grade 3, Poor = Grade 2 and Unable to do = Grade 1.

3) Standing for 45 seconds with eyes open and closed on fixed surface and sponge

These tests took approximately 10 minutes to complete.

4.9.3 Questionnaire of duration and frequency of activity participation

The International Physical Activity Questionnaire (IPAQ) is a physical activity questionnaire, which includes items on the duration and frequency of participating in various activities of young and middle aged adults when they engage themselves in activities related to employment, transportation, housework, recreation and sport. Participants took the questionnaire and completed it at home and posted it back. Completing the questionnaire normally took around 20 minutes.

4.10 Assessment variables from the outcome measures

The following variables were assessed from the FSA mat that was fixed on the treadmill.

4.10.1 Temporal variables from the antero-posterior center of pressure (CoP-X)

The difference in time from maximum to minimum for both odd and even steps separately - stance time

1) Time difference from min to max for odd and even steps separately- swing time
2) Time from max of odd step to max of even step- stride time
3) Time from min of odd step to min of even step- stride time
4) Time from max of even step to max of odd step- step time
5) Time from min of even step to min of odd step- step time

4.10.2 Spatial variables from the antero-posterior center of pressure (CoP-X)

1) X-Y coordinates at max of odd step- average position of CoP for odd steps in antero-posterior directions
2) X-Y coordinates at max of even step- average position of CoP for even steps in antero-posterior
3) Amplitude difference from time of min to max for odd steps-
4) Amplitude difference from time of max to min for odd steps-

5) Amplitude difference from time of min to max for even steps- step length

6) Amplitude difference from time of max to min for even steps- step length

4.10.3 Temporal variables from the Medio-lateral center of pressure (CoP-Y)

1) Difference in time from the start of upper plateau to end of upper plateau. This is equal to the odd step in CoP – X – upper single support time

2) Difference in time from the start of lower plateau to end of lower plateau. This is equal to the even step in CoP – X) – lower single support time

3) Time difference from T1 (old T1) to T2 i.e. time duration of transition to upper plateau- swing upper time

4) Time difference from T3 to T4 i.e. time duration of transition to lower plateau- swing lower

4.10.4 Spatial variables from the Medio-lateral center of pressure (CoP-Y)

1) Average CoP – Y coordinates of upper plateau- position of CoP in medio lateral direction for odd steps.

2) Average CoP – Y coordinates of lower plateau- position of CoP in medio-lateral direction for even steps.

3) Magnitude between upper to lower average coordinate – i.e. step width when swinging odd leg- step width

4) Magnitude between lower to upper average coordinate – i.e. step width when swinging even leg – step width

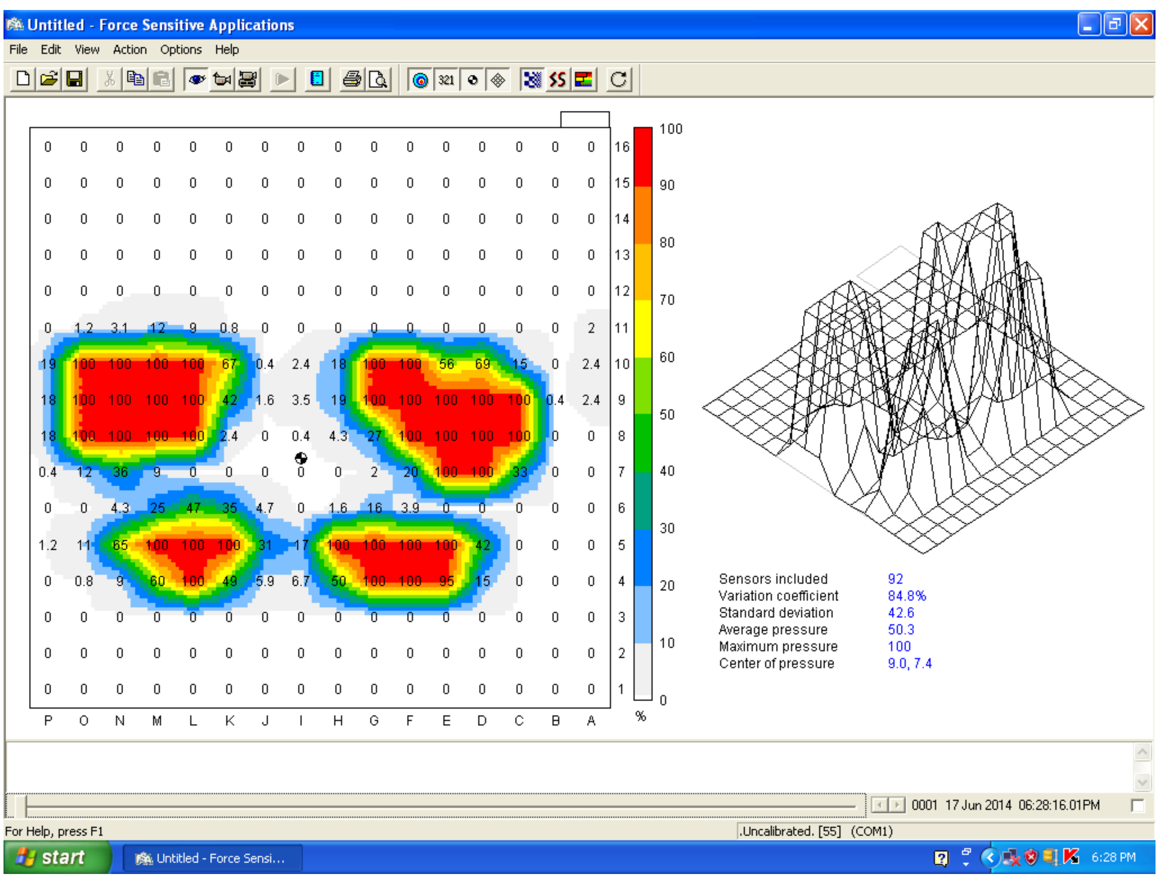
4.11 Data analysis

The dependent variables mentioned above were derived from custom built scripts for Mat Lab (Math Works, Natick, MA) from the data that was recorded.

4.11.1 Standing Balance

COP excursions during both antero-posterior and medio-lateral directions were recorded during the various balance tasks. The root mean square (RMS) of the COP was used as a measure of stability. Figure 7 shows a snap shot of right and left foot placement on FSA mat.

Figure 7: Standing profile and CoP excursions on FSA mat

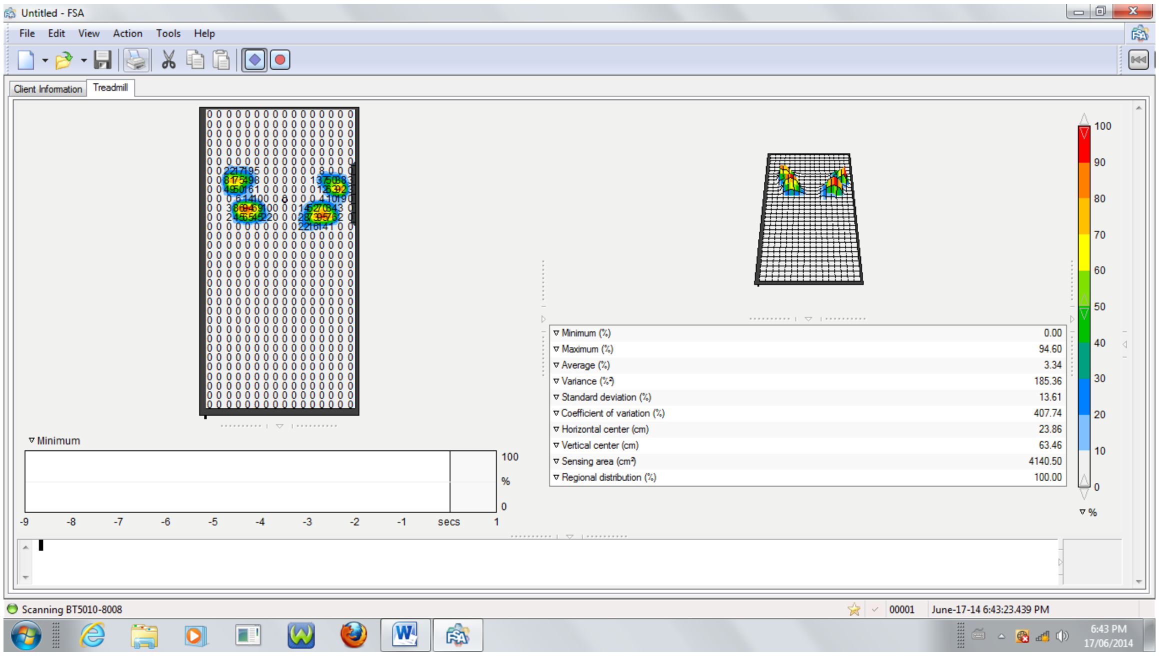


4.11.2 Gait Variables

Both the spatial (step length and step width) and temporal variables (swing time, step time and single support time) were derived from the COP in both AP and ML directions from the FSA mat under the treadmill mat. Figure 8 demonstrates the experimental set up consisting of treadmill, computer screen and air mouse on helmet. Figure 9 shows the treadmill mat recording for the quantification of spatial and temporal variables.

Figure 8: Experimental set up

Figure 9: Treadmill pressure mat recording



4.11.3 Visual Tracking

Reference and user signals were used to analyse the quality of visual tracking. The coefficient of determination (CoD) was obtained by using a non linear least square algorithm that was used to get a sine wave function of the user and reference signals (Figure 10). Figure 11show the closed loop visual tracking performance during standing on a fixed surface.

Figure 10: Analysis of closed loop visual tracking performance

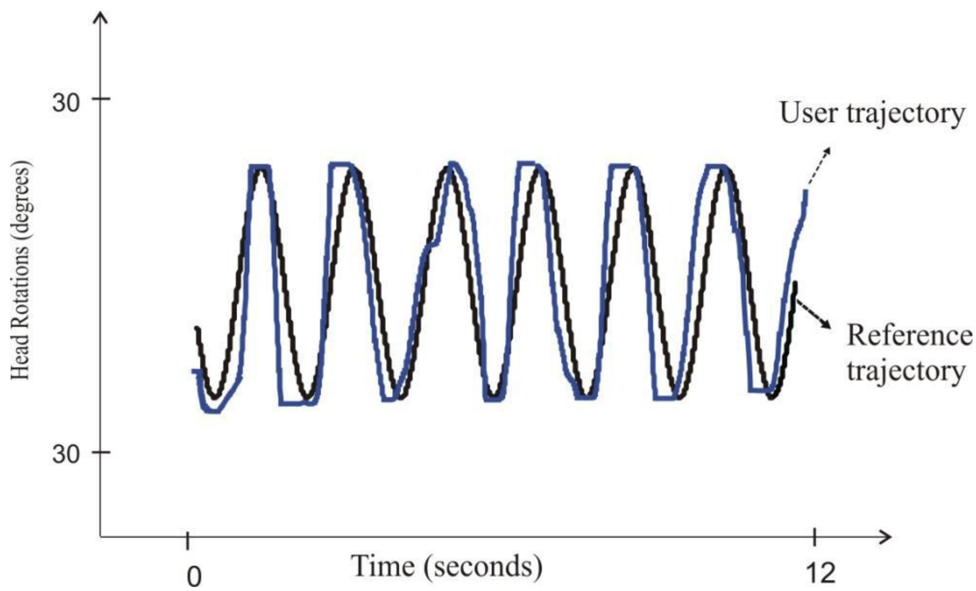
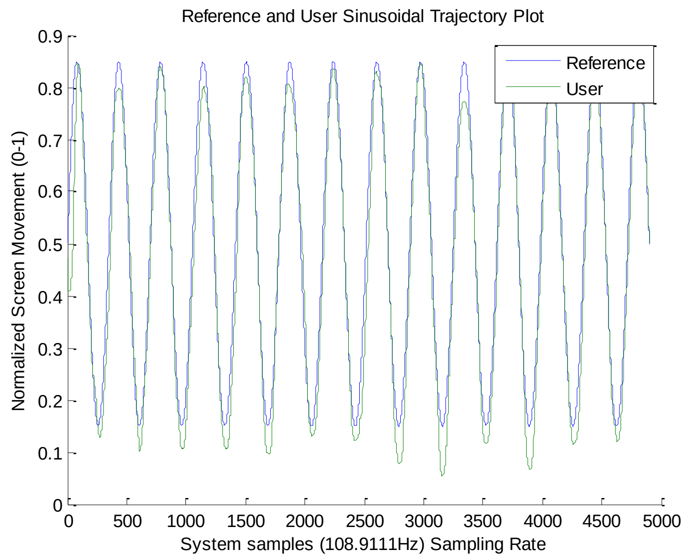


Figure 11: Closed loop visual tracking performance on a fixed surface



4.11.4 Cognitive performance measures

Figures 12 to 14 show the performance of Game 1 on fixed, sponge and treadmill surfaces. Figures 15 to 17 show the performance of Game 2 on fixed, sponge and treadmill surfaces

Figure 12: Performance measures of Game 1- Fixed surface

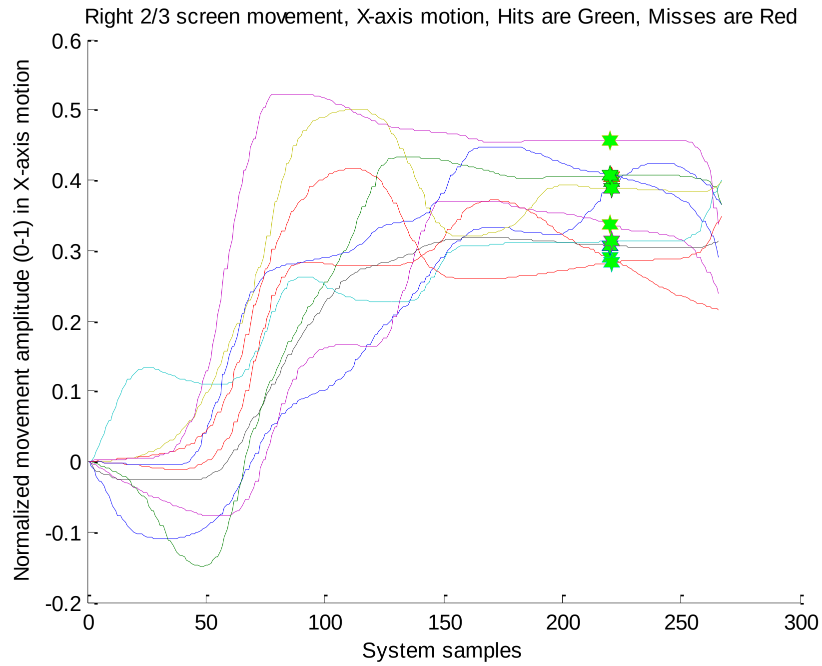


Figure 13: Performance measures of Game 1- Sponge surface

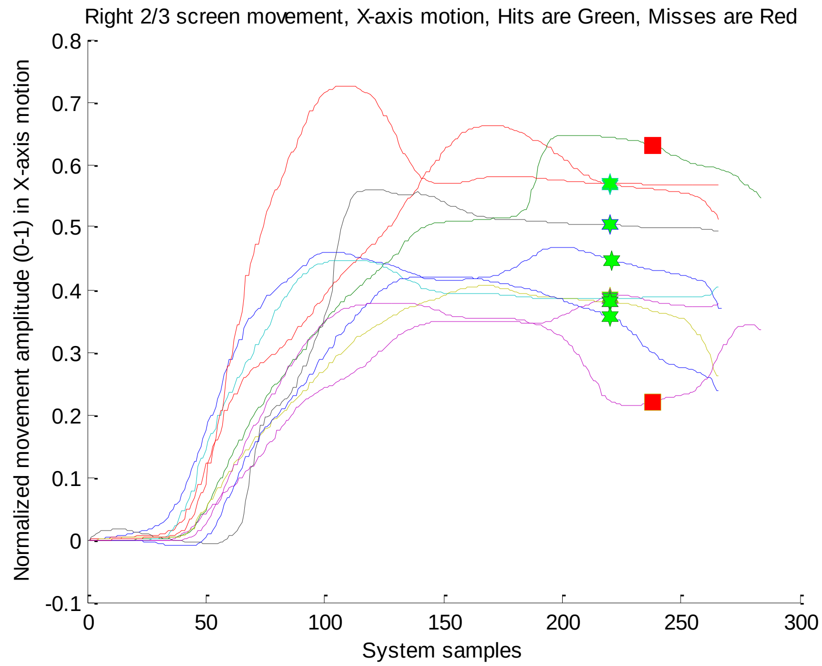


Figure 14: Performance measures of Game 1- Treadmill

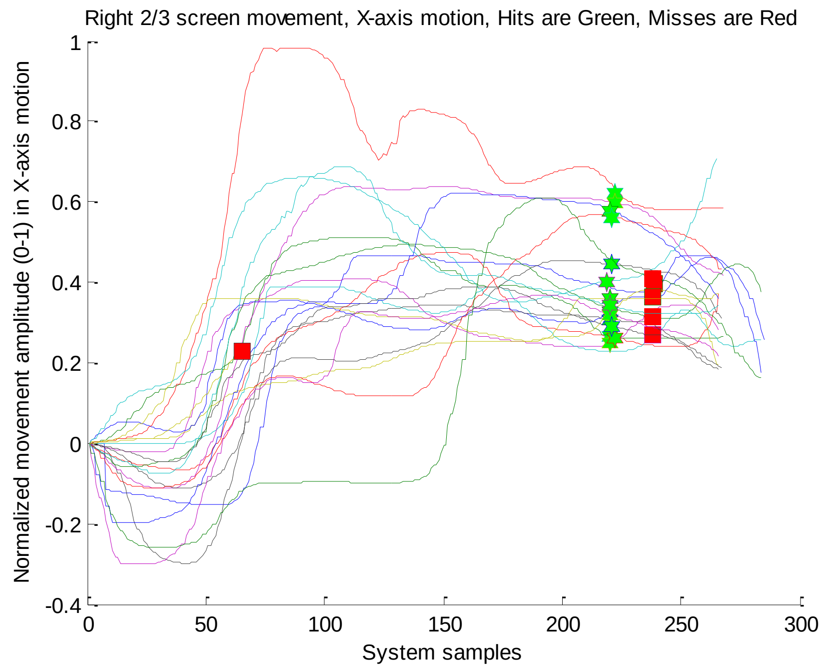


Figure 15: Performance measures of Game 2- Fixed surface

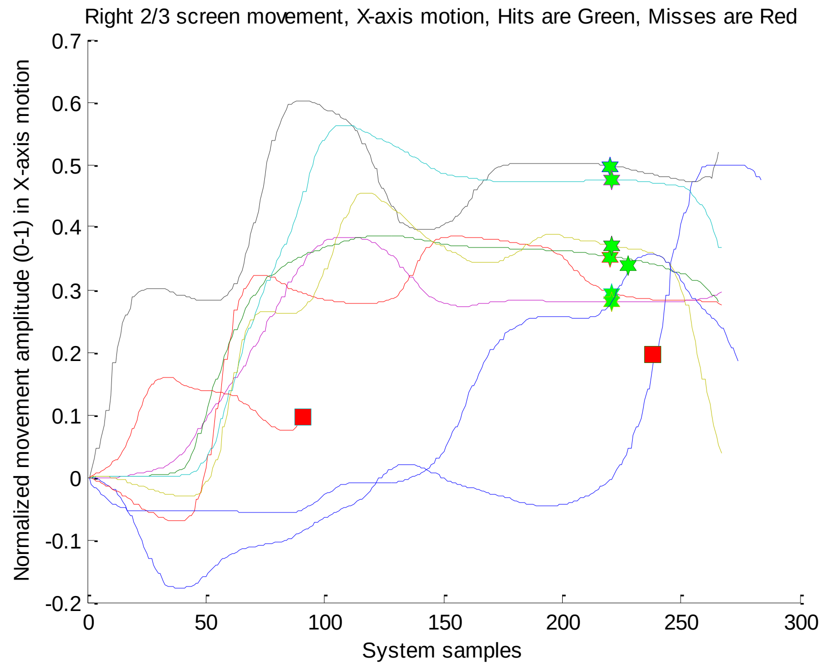


Figure 16: Performance measures of Game 2- Sponge surface

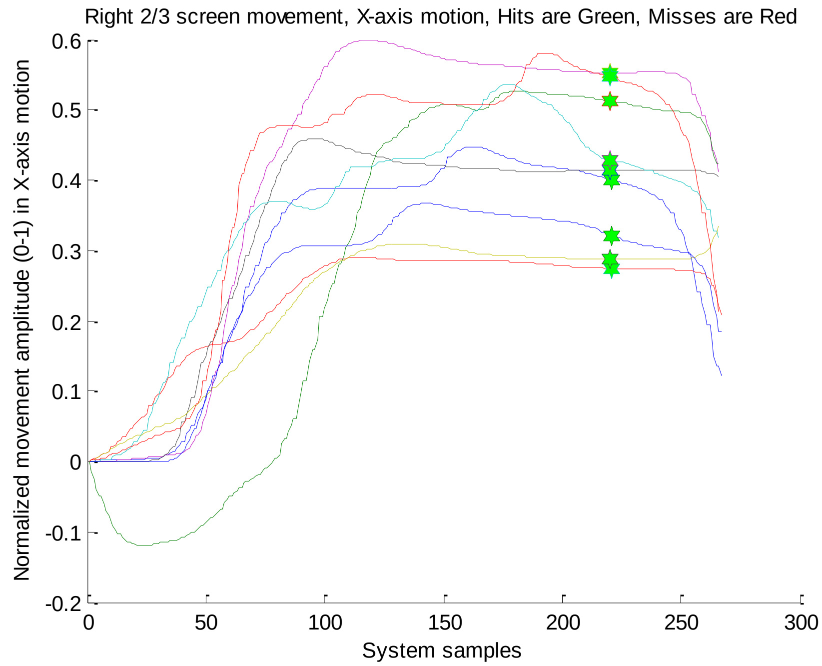
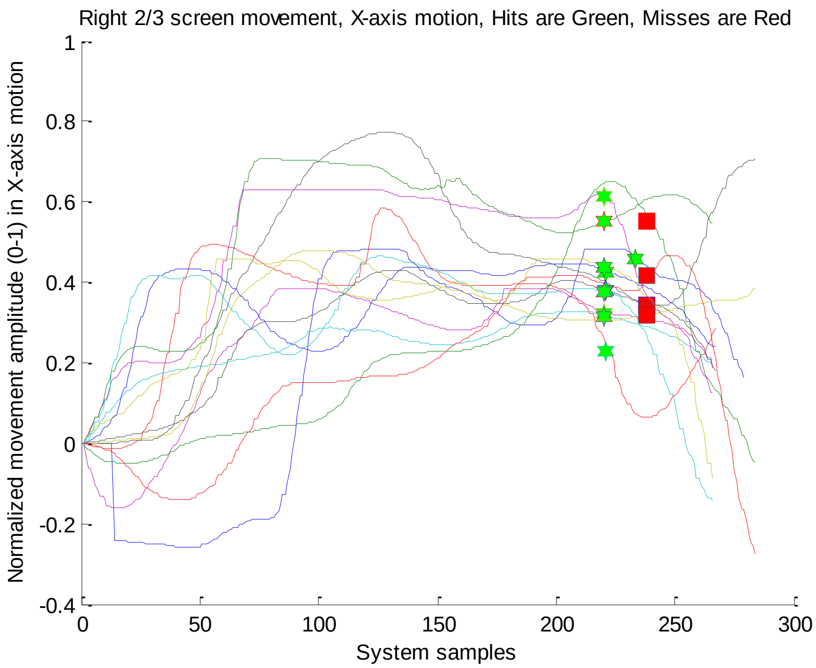


Figure 17: Performance measures of Game 2- Treadmill



4.12. Statistical Analysis

Two-way between groups Analysis of Variance (ANOVA) was done to compare the performance of active young adults with the performance of older adults. Unpaired student t tests were performed to determine the difference between old and young adult groups during single task conditions.

Chapter 5: Results

Thirty healthy and active young adults were included in this study as participants. The results of young adults were compared with the results of thirty healthy older adults. The demographic details and results of tandem walk test are provided in Table 1.

Table 1: Demographic information of study participants

Demographic details	Young Adults	Older Adults
Age (Mean ± SD) years	26.7± 2 years	61.4± 4.4 years
Gender (Male: Female)	20:10	26: 4
Tandem Walk Grade (X/5)	3.93 ±1.2	2.75±0.48

5.1 Single task standing balance

Unpaired student t tests were performed to find the differences between healthy young adults and older adults with respect to balance during single task standing on a fixed surface and while standing on a sponge surface. Standing balance was quantified by the RMS of Center of Pressure in both the Antero-Posterior and Medio-Lateral directions.

Larger RMS values indicated poor balance.

Figure 18 illustrates the histograms containing means (SEM) of RMS values of CoP of young and old adults in both AP and ML directions in fixed and sponge surfaces during eyes open and eyes closed conditions.

Figure 18: RMS values of CoP -AP and ML directions in fixed and sponge surfaces

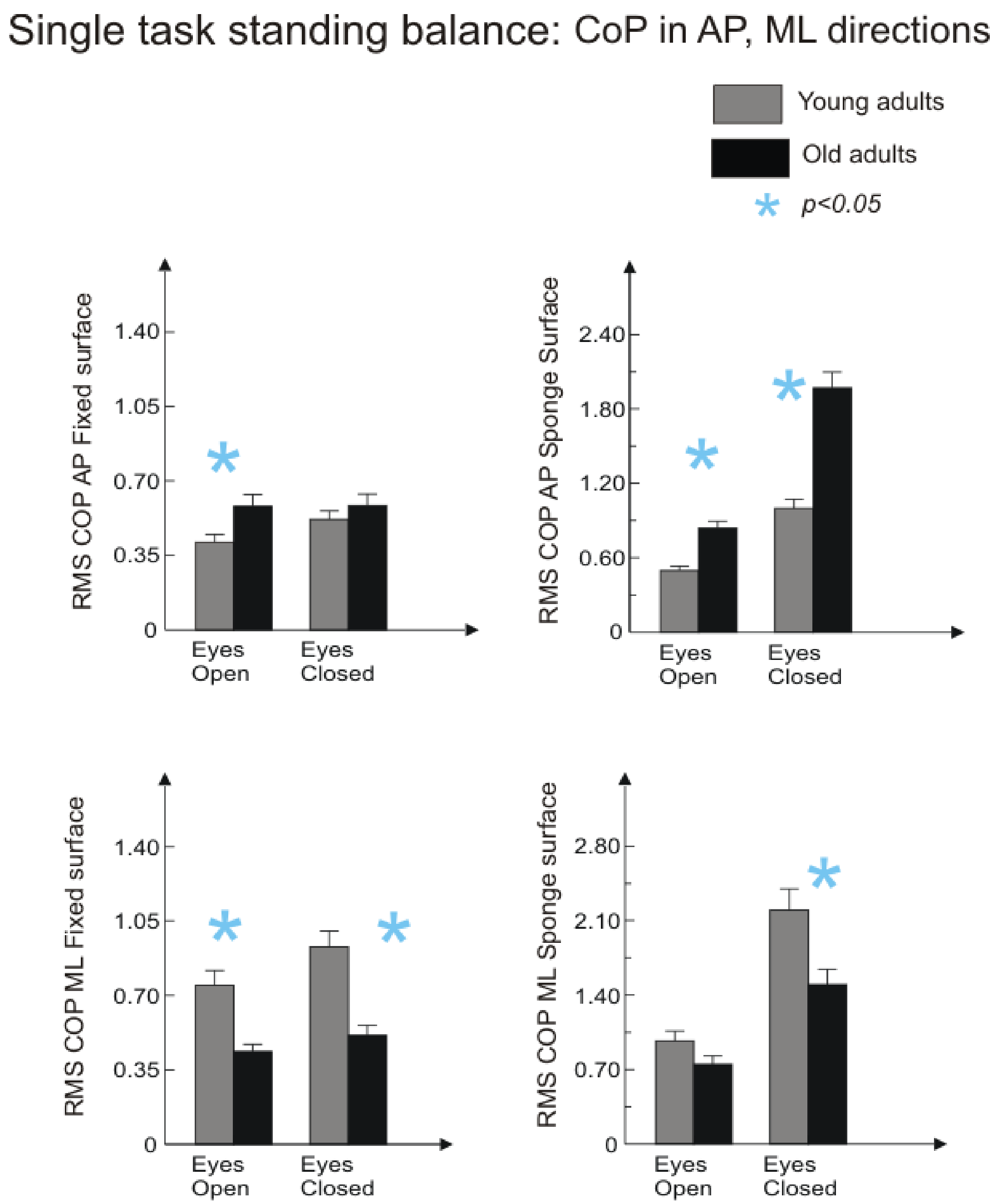


Table 2 represents the p values and t statistics of CoP of young and old adults in both AP and ML directions in fixed and sponge surfaces during the eyes open condition.

Table 2: CoP in AP and ML directions on fixed and sponge surfaces standing with eyes open

Variables	Physical Load during eyes open condition	'p' value, t-statistic and df
RMS CoP- AP (cm)	Fixed Surface	$p<0.01$, $t=-2.64$, $df=58$
RMS CoP- ML (cm)		$p<0.00$, $t= 4.18$, $df=58$
RMS CoP- AP (cm)	Sponge Surface	$p<0.00$, $t= -4.5$, $df=58$
RMS CoP- ML(cm)		*p>0.05*

$\alpha= 0.05$

Table 3 represents the p values and t statistics of CoP of young and old adults in both AP and ML directions in fixed and sponge surfaces during the eyes closed condition.

Table 3: CoP in AP and ML directions on fixed and sponge surfaces standing with eyes closed

Variables	Physical Load during eyes closed condition	'p' value, t-statistic and df
RMS CoP- AP (cm)	Fixed Surface	*p>0.05*
RMS CoP- ML (cm)		p<0.00, t= 4.93, df=58
RMS CoP- AP (cm)	Sponge Surface	p<0.00, t= -6, df=58
RMS CoP- ML(cm)		p<0.00, t= 2.94, df=58

α= 0.05

The results demonstrate that in general younger adults demonstrated better balance in the AP direction, while older adults demonstrated better balance in the ML direction. During eyes open condition on the fixed surface, younger adults showed significantly lower RMS of CoP values than older adults in the AP direction while older adults showed significantly lower RMS of CoP in the ML direction. During eyes open condition on the sponge surface, younger adults showed significantly lower RMS of CoP in the AP direction while there was no significant change in the ML direction.

On the fixed surface during eyes closed condition there was no significant group difference. However, older adults showed a significantly lower RMS in the ML direction.

During the eyes closed condition on the sponge surface, younger adults showed significantly lower RMS values than older adults in the AP direction, while older adults showed significantly lower RMS in the ML direction.

5.2 Single task walking on treadmill

Foot contact pressures were used to determine when the foot comes in contact with the FSA mat on the treadmill. This allowed us to determine the step time, single support time and swing time. The center point of the foot contact was used to determine the distances in step length and step width. The CoV and average values of the spatial and temporal parameters were used to determine the walking performance with more CoV values indicating poor walking performance. The CoV is more indicative of stability while the averages are more indicative of locomotor pacing and rhythm.

Figures 19 & 20 show histograms of the mean (SEM) of the averages of step width, step length and step time and the mean (SEM) of the CoVs of step width, step length, step time, swing time and single support time while walking on the treadmill.

Figure 19: Averages of step width, step length and step time

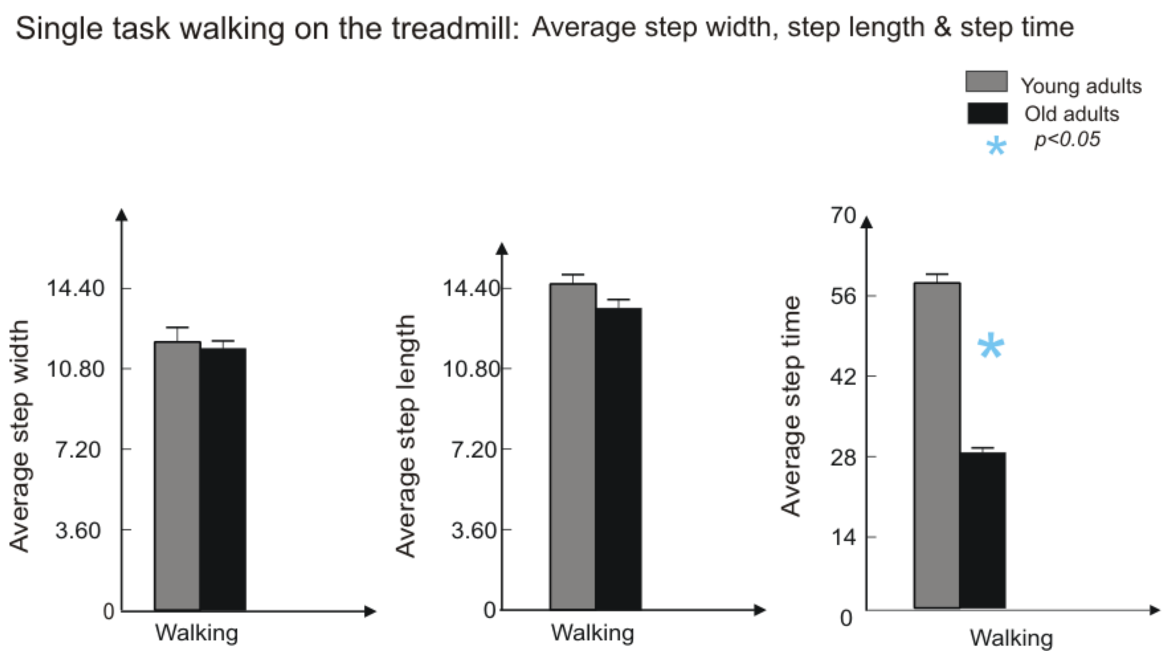


Figure 20: CoVs of step width, step length, step time, swing time and single support time

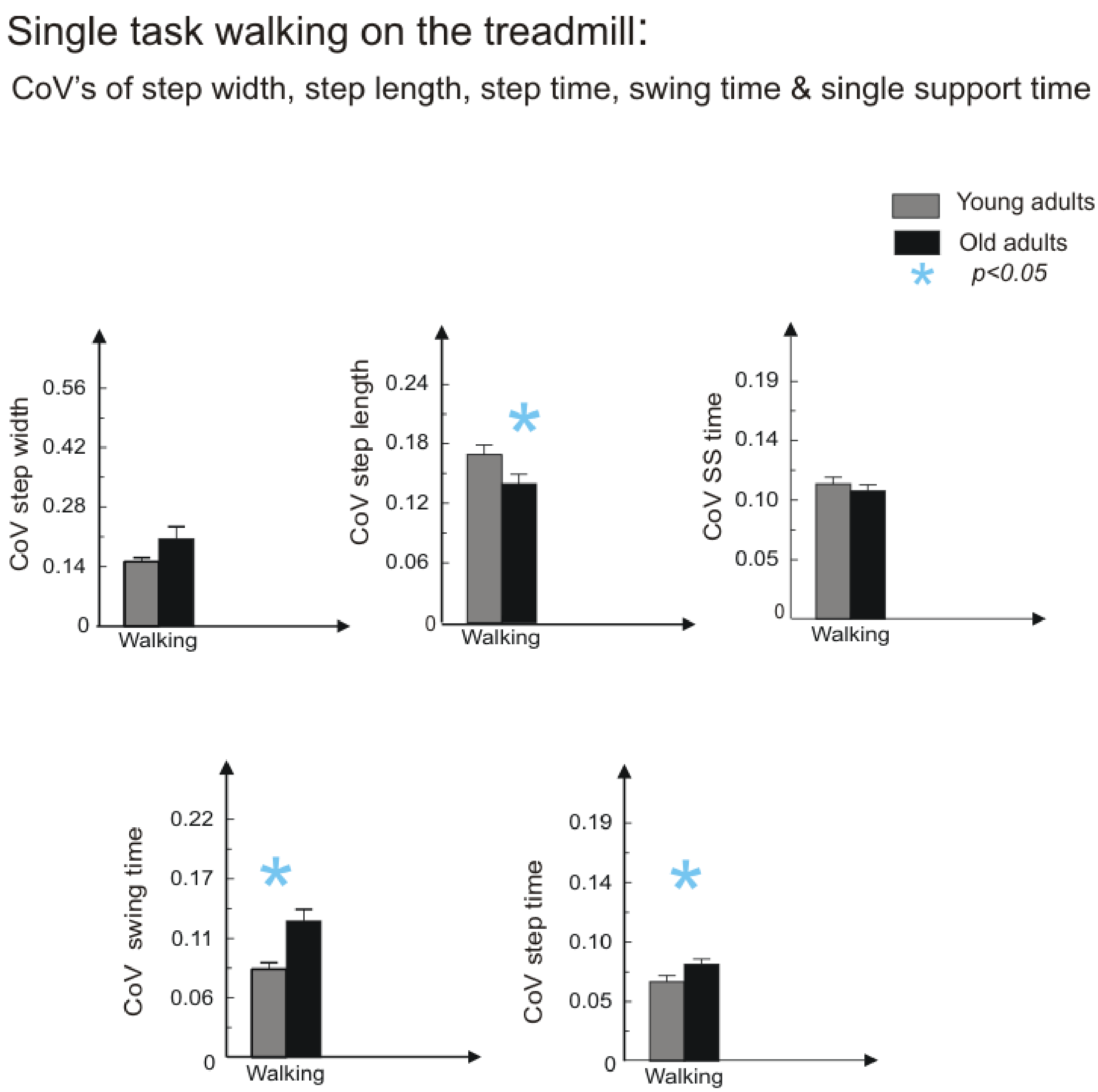


Table 4 shows the *p* values and t statistics of the averages and CoVs of spatial and temporal gait variables during single task walking between young and old adults.

The results showed that there was no significant age effect in the average of the spatial variables of step length and step width while walking on a treadmill. The results did demonstrate a significant age effect in the average of the temporal variable step time with young adults demonstrating a longer step time than older adults. The results also showed a significant age effect in the CoV of step length with younger adults showing a significantly greater CoV while step width did not demonstrate a significant age effect.

The results further showed an age effect on CoV in the temporal variables of step time and swing time with older adults showing significantly greater CoV during these variables than young adults. There was no significant difference found in the CoV during single support time.

Table 4: Averages and CoVs of gait variables during single task walking

Walking alone (Single task)	'p' values, t statistics and df
Step Length	
Average	$p>0.05$
Co-efficient of variation	$p<0.00$, t= 15.55, df= 61
Step Width	
Average	$p>0.05$
Co-efficient of variation	$p>0.05$
Step time	
Average	$p<0.00$, t= 17.27, df= 61
Co-efficient of variation	$p<0.03$, t= -2.11, df= 61
Swing time	
Co-efficient of variation	$p<0.00$, t= -3.65, df= 61
Single support time	
Co-efficient of variation	$p>0.05$

$\alpha= 0.05$

5.3 Single task Cognitive games

Participants played two cognitive games. The first game was a simple game without a distracter while the second game was of moderate difficulty and included a distracter. The success rate, execution time and response time while standing on a fixed surface were used as performance indicators.

Figure 21 show histograms of the success rate, response time and execution time during simple and moderate games between old and young adults while standing on a fixed surface.

Figure 21: Success rate, response and execution time -Standing

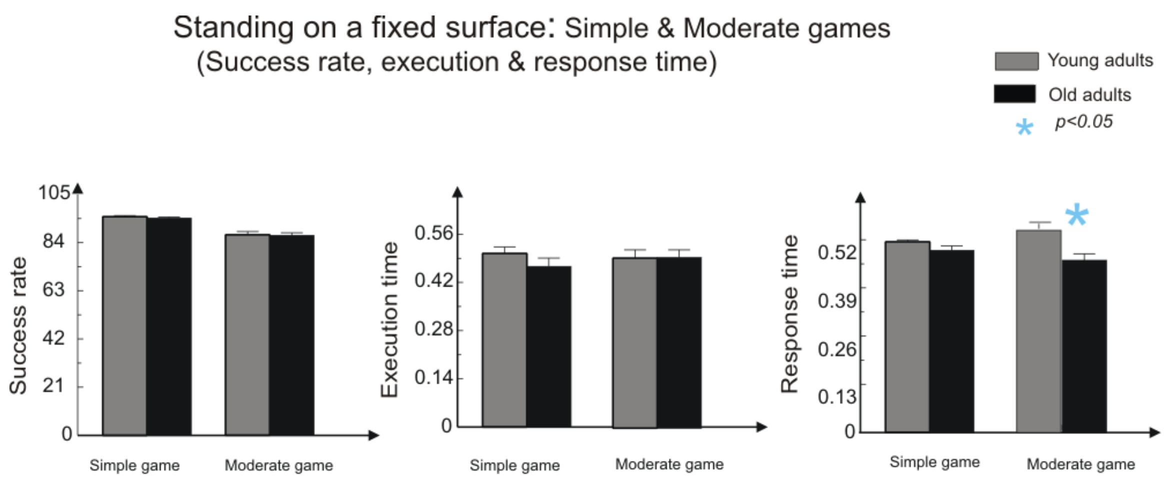


Table 5 shows the p values and t statistics of the success rate, response time and execution time during simple and moderate games between old and young adults while standing on a fixed surface. The results generally demonstrated that there was no difference between the performance of healthy young adults and older adults during single task cognitive games. Only response time showed significance with younger adult demonstrating a longer response time (59 ms versus 53ms) during the moderate game with distractors.

Table 5: Success rate, response and execution time during standing on a fixed surface

Standing on fixed surface	'*p*' values, t statistics and df
Simple game	
Success Rate	$p>0.05$
Response Time	$p>0.05$
Execution Time	$p>0.05$
Moderate game	
Success Rate	$p>0.05$
Response Time	$p<0.00$, t= 2.32, df= 61
Execution Time	$p>0.05$

α= 0.05

5.4 Single task visual tracking

The coefficient of determination (CoD) was used to determine the performance of the visual tasks. The visual tracking task was a closed loop task. The task was performed while participants were standing on a fixed surface.

Figure 22 shows the histograms for CoD during closed loop visual tracking tasks between old and young adults while standing on a fixed surface.

Figure 22: CoD during closed loop visual tracking task while standing on a fixed surface

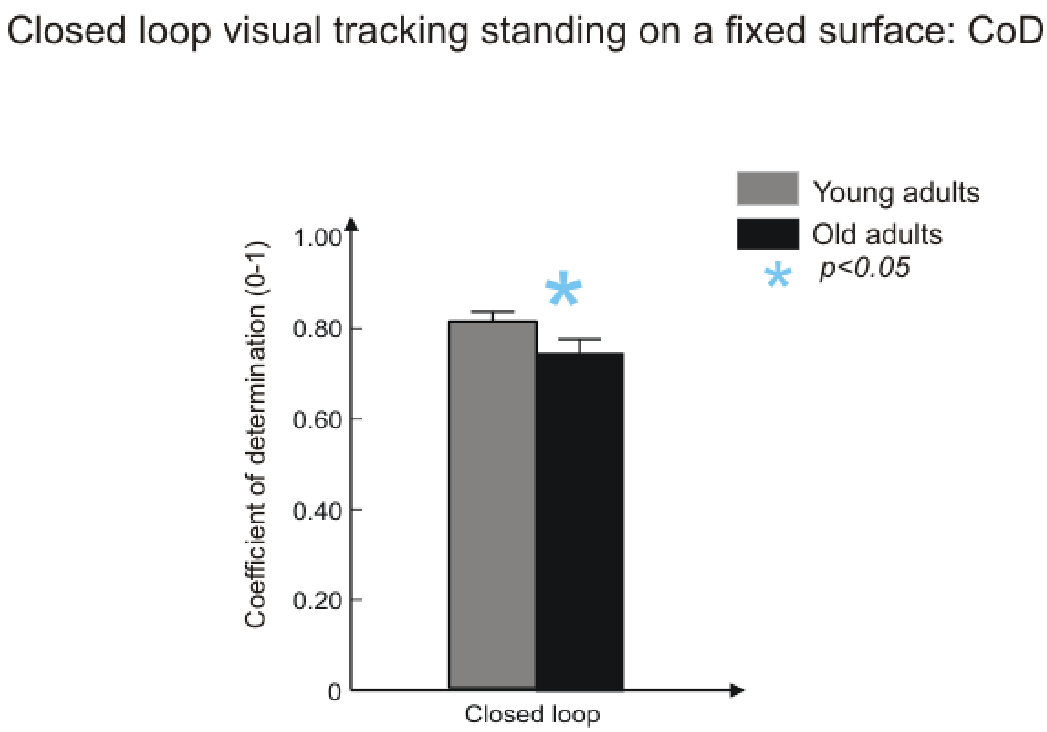


Table 6 shows the p values, t statistics and degrees of freedom of a t test between healthy young adults and older adults while performing a visual tracking task standing on a fixed surface. The results revealed that younger adults performed better during the closed loop task. Young adults demonstrated a significantly higher CoD (0.81 versus 0.73) during the closed loop task.

Table 6: CoD during closed loop tracking while standing on a fixed surface

Variable and Visual tracking task	Physical load	'*p*' values and t statistics
CoD during Closed loop condition	Fixed Surface	$p<0.04$, t= 2.01, df= 61

α= 0.05

Summary of findings during single task conditions

Younger adults demonstrated better standing balance in the antero-posterior direction while older adults performed better in the medio-lateral direction in both fixed standing and sponge standing during both eyes open and eyes closed conditions. During treadmill walking only the co-efficient of variation of step length showed a significant difference in favour of the young adults. The co-efficient of variation did not show any changes in either step length or step width. During the temporal parameters the co-efficient of variation was greater in older adults during step time and swing time while it did not show any changes in single support time. The average of step time was greater in younger adults. During the cognitive tasks, younger adults were significantly better during the closed loop visual tracking task while both the cognitive tasks did not show a difference except during the response time of the moderate game where younger adults demonstrated a longer response time.

5.5 Dual task walking, cognitive tasks, visual tracking tasks and age effects

5.5.1 Balance and dual tasking

Two way ANOVA's were performed to find out the dual task effect and age effect. Different tasks were performed during standing on a fixed surface and sponge surface. The tasks performed were standing with eyes open, standing with eyes closed, closed loop tracking task, simple cognitive game and moderate cognitive game. The more the RMS of CoP the more the postural sway is.

Figure 23 show histograms of the means (SEM) of RMS-CoP during different tasks like standing on a fixed surface and sponge surface in both AP and ML directions.

Figure 23: RMS-CoP in AP directions during standing on fixed and sponge surfaces

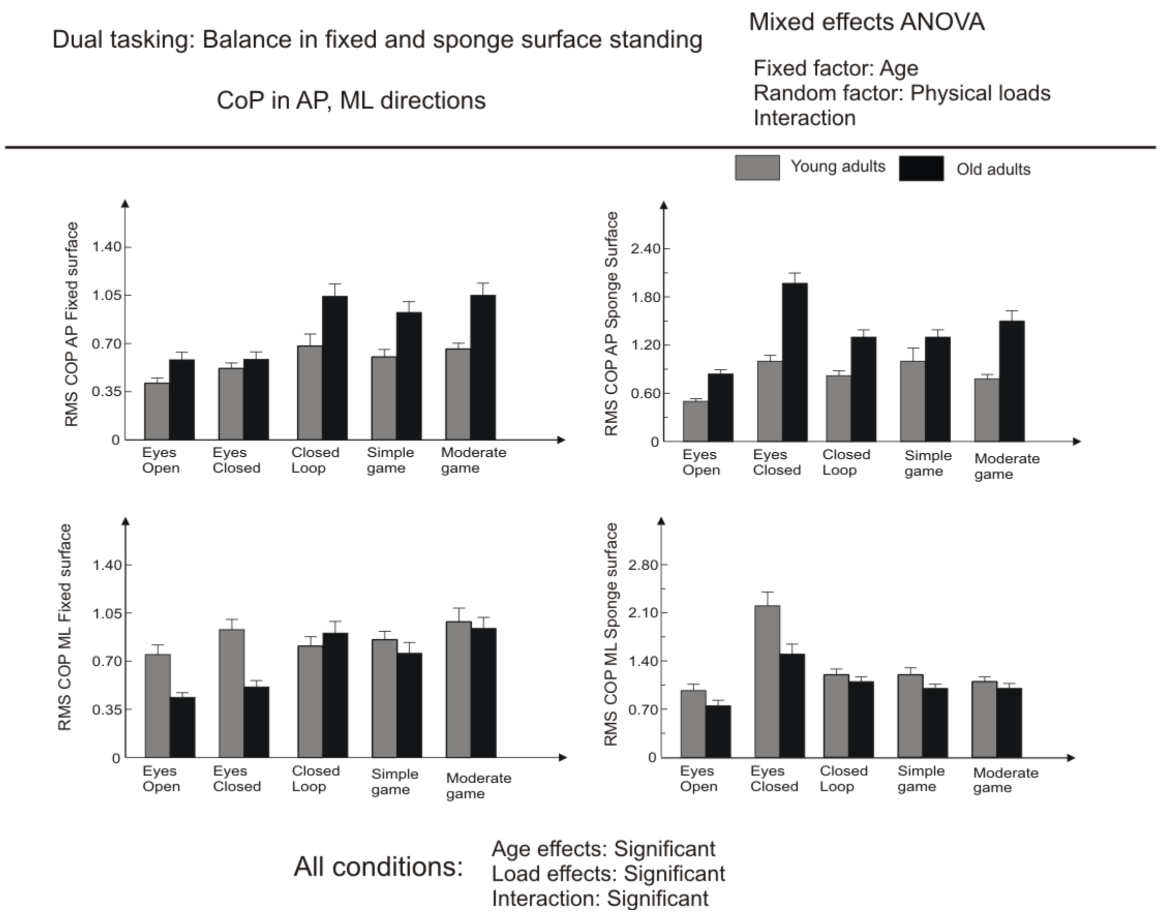


Table 7 shows the results of two-way ANOVA's performed to find out the age effect, the difference between single and dual task conditions in both young and old adults and an interaction effect with respect to the RMS of the CoP in the Antero-Posterior direction during standing.

Table 7: RMS of CoP in Antero-Posterior direction of fixed and sponge surface

Variable and surface condition	Eyes open, closed loop, simple and moderate game	Age	Interaction
Fixed Surface RMS of CoP-AP (cm)	$p< 0.001$ F= 17.58, df= 3.80 n_p^2=0.22	$p< 0.001$ F = 20.17, df= 1 n_p^2=0.24	$p< 0.05$ F = 2.83, df= 3.80 n_p^2=0.04
Sponge Surface RMS of CoP-AP (cm)	$p< 0.001$ F = 25.9, df= 4.52 n_p^2=0.29	$p< 0.001$ F= 36.07, df= 1 n_p^2=0.37	$p< 0.001$ F = 4.71, df= 4.52 n_p^2=0.07

(n_p^2= Effect size) and α= 0.05

Table 8 shows the results of two-way ANOVA's performed to find out the age effect, the difference between single and dual task conditions in both young and old adults and an interaction effect with respect to the RMS of the CoP in the medio-lateral direction during standing. The different tasks were performed during standing on a fixed surface and sponge surface. The tasks performed were standing with eyes open, standing with eyes closed, closed loop tracking task, simple cognitive game and moderate cognitive game.

Table 8: RMS-CoP in ML directions during standing on fixed and sponge surfaces

Variable and surface condition	Eyes open, closed loop, simple and moderate game	Age	Interaction
Fixed Surface RMS of CoP-ML (cm)	*p*< 0.001 F= 11.9, df= 4.20 n_p^2=0.01	*p*< 0.05 F= 7.95, df= 1 n_p^2=0.11	*p*< 0.001 F = 4.81, df=4.20 n_p^2=0.07
Sponge Surface RMS of CoP-ML (cm)	*p*< 0.001 F = 32.34, df= 2.76 n_p^2=0.34	*p*< 0.05 F= 8.77, df= 1 n_p^2=0.12	*p*< 0.05 F = 3.61, df=2.76 n_p^2=0.05

(n_p^2= Effect size) and α= 0.05

It can be generally observed from the results that on both the fixed and sponge surfaces both young and older adults demonstrated more standing stability during control standing and the stability in both AP and ML directions kept decreasing as cognitive and visual tracking tasks were added. Young adults demonstrated better standing stability as compared to older adults in the AP direction while older adults demonstrated better standing balance in the ML direction.

Figure 18 shows the RMS of CoP in the anterior-posterior direction while standing on a fixed surface and while standing on a sponge surface. The results showed a significant effect due to task condition from single task standing alone to dual task conditions where a cognitive or visual tracking task was added while standing. The significant effect due to task condition with eyes open was much lower than other conditions in both fixed and sponge surfaces and in both AP and ML directions. There was also a significant age effect with young adults performing significantly better than older adults in all tasks conditions. The age effect was demonstrated in both fixed and sponge surfaces. With respect to direction there was a significant age effect in both AP and ML direction with young adults doing better in AP direction and older adults doing better in the ML direction. The results also showed an interaction effect.

Figure 18 also shows the RMS of CoP in the medio-lateral direction while standing on a fixed surface and while standing on a sponge surface. The results showed a significant effect due to task condition from single task standing alone to dual task conditions where a cognitive or visual tracking task was added while standing. There was also a significant age effect with older adults performing significantly better than younger adults in all tasks conditions. There was also an interaction effect observed.

5.5.2 Spatio-temporal gait variables during cognitive tasks (dual task)

The CoV and average values of spatial and temporal parameters were used to determine the gait performance with lesser CoV values indicating better gait performance.

Figures 24 & 25 show histograms of the averages and CoVs during control walking and dual task walking (walking, cognitive games and closed loop visual tracking task)

Figure 24: Average step width, length and step time during walking, cognitive games and visual tracking task

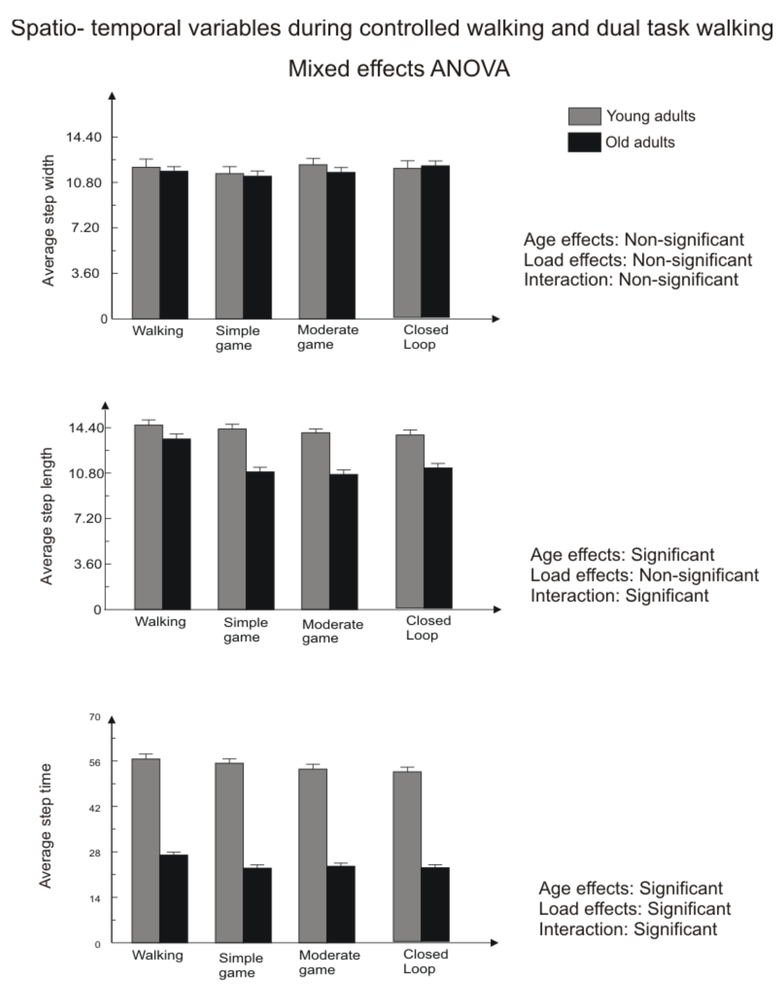


Figure 25: CoV of temporal variables during walking, cognitive games and visual tracking task

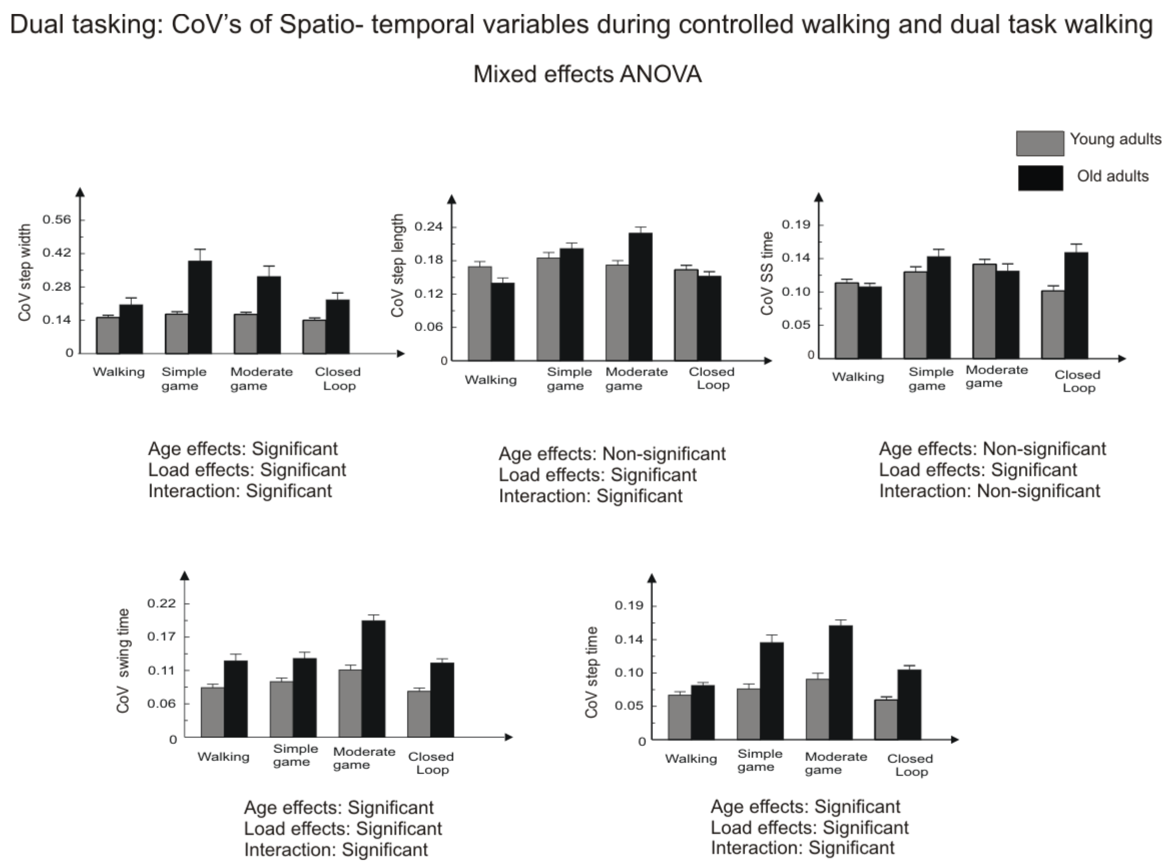


Table 9 shows the results of two way ANOVAS's performed to find out the age effect, the difference between single and dual task conditions in both young and old adults and interaction effect during the performance of different cognitive tasks while walking on a treadmill.

Table 9: Two way ANOVAS's performed between single and dual task conditions in both young and old adults

Spatial and temporal variables	Dual task: Walking only, Game 1 & Game 2	Age	Interaction
Step Length			
Average	*p>0.05*	*p*<0.001 F = 74.82, df= 1 n_p^2=0.55	*p*<0.044 F = 3.21, df= 2.00 n_p^2=0.05
Co-efficient of variation	*p*<0.001 F = 18.38, df= 1.93 n_p^2=0.23	*p>0.05*	*p*<0.001 F = 14.02, df= 1.93 n_p^2=0.18
Step Width			
Average	*p>0.05*	*p>0.05*	*p>0.05*
Co-efficient of variation	*P*<0.006 F = 5.31, df= 2.00 n_p^2=0.08	*p*<0.001 F = 40.41, df= 1 n_p^2=0.39	*P*< 0.025 F = 3.82, df= 2.00 n_p^2=0.05
Step time			
Average	*p*<0.001 F = 9.50 (2,27) n_p^2=	*p*<0.001 F = 50.30 (2,27) n_p^2=	*p<0* .003 F = 4.35 (2,27) n_p^2=
Co-efficient of variation	*p*<0.001 F = 18.86 (2,27) n_p^2=	*p*<0.001 F = 27.78 (2,27) n_p^2=	*p*<0.001 F= 9.92 (2,27) n_p^2=
Swing time			
Co-efficient of variation	*p*<0.001 F = 20.96, df= 1.98 n_p^2=0.25	*p*<0.001 F = 51.16, df= 1 n_p^2=0.45	*p*< 0.016 F = 4.26, df= 1.98 n_p^2=0.06
Single Support Time			
Co-efficient of variation	*p*<0.001 F = 10.03, df= 2.00 n_p^2=0.14	*p>0.05*	*p>0.05*

(n_p^2= Effect size) and α= 0.05

Younger adults in general demonstrated better walking stability than older adults. It was also demonstrated that the walking stability decreased as dual task conditions were performed with the moderate cognitive task decreasing walking stability more than the simple cognitive task.

The results did not demonstrate a significant dual task effect for the averages in both young and older adults during the spatial parameters of step width and step length. A significant age effect was seen in the average step length with young adults demonstrating a greater step length than older adults during all conditions. The average of step width did not demonstrate an age effect. There was a significant interaction observed for the average of step length while not for the average of step width.

Significant dual task effects were observed in both young and older adults for the CoV of both step length and step width. During both step length and step width, older adults showed lesser CoV during walking alone than any of the dual task conditions. Younger adults showed lesser CoV during both step length and step width on all dual task conditions except during closed loop walking where the CoV was marginally higher. The CoV of step width showed a significant age effect with young adults demonstrating a lesser CoV than older adults during all conditions while the CoV of step length did not show an age effect. Significant interactions were observed in the CoV during both step width and step length.

The average step time showed a significant dual task effect in both young and older adults with the step time reducing in both groups during dual tasks when compared to walking alone. The average step time also showed a significant age effect with young adults demonstrating a greater step time during all conditions. A significant interaction was also observed during step time.

Significant dual task effects were observed for both young and old adults in the CoV of step time, swing time and single support time. During swing time, stride time and single support time, young adults showed a decreased swing time during walking alone, than during all the dual task conditions except with the closed loop visual tracking task where it was increased. The same trend was observed in older adults during swing time. During step time and single support time the CoV was consistently significantly higher during the duals tasks than during walking alone. Both CoV of step time and swing time showed an age effect with younger adults demonstrating significantly lower CoVs than older adults in all conditions. The CoV of single support time did not demonstrate an age effect. Significant interactions were observed in the CoV during step time and swing time but not during single support time.

5.5.3 Spatio-temporal gait variables during visual tracking task (dual task)

Table 10 shows the results of two way ANOVAS's performed to find out the dual task effect, the age effect and interaction effect in both young and old adults, during the performance of a closed loop visual tracking task while walking on a treadmill.

The results showed a significant dual task effect for the average in both young and older adults during step length but not step width. In both young and old adults the average step length was lower during the dual task walking than during control walking. The average of step length demonstrated a significant age effect with young adults demonstrating a greater step length than older adults during the closed loop visual tracking task while walking. The average of step width did not demonstrate an age effect.

No significant interactions were observed for step length and step width during closed loop visual tracking task while walking.

Significant dual task effects were observed for both young and older adults for the CoV of step length but not step width. During step length, young adults demonstrated a lesser CoV during dual task walking than when walking alone. However, older adults demonstrated a lesser CoV during walking alone than during dual task walking. The CoV of step width showed an age effect with young adults demonstrating a lesser CoV than older adults during the closed loop visual tracking and walking while the CoV of step length did not show an age effect. Significant interactions were observed in the CoV during step length but not step width.

Both young and older adults demonstrated a significant dual task effect during the average of step time. In both young and old adults the average step time was lower during the dual task walking than during control walking. The average step time demonstrated a significant age effect with younger adults showing a greater step length than older adults. Both groups also showed a significant interaction effect.

Significant dual task effects were observed for both young and old adults in the CoV of step time and single support time but not swing time. Young adults demonstrated a lesser CoV during dual task walking than during control walking during both step time and single support time. However, older adults showed lesser CoV during the control walk than during the dual task walking in both step time and single support time. The CoV of step time, swing time and single support time showed an age effect with younger adults demonstrating significantly lower CoVs than older adults in all three temporal variables while performing a closed loop visual tracking task and walking against control walking. The results also showed significant interactions in the CoV during step time and single support time but not during swing time.

Table 10: Two way ANOVAS's in both young and old adults during visual tracking task in treadmill walking

Spatial and temporal variables	Visual task, Walking only & Closed Loop	Age	Interaction
Step Length			
Average	p<0.001 F= 13.13, df= 2.00 n_p^2=0.17	p<0.001 F= 22.55, df= 1 n_p^2=0.27	*p>0.05*
Co-efficient of variation	p< 0.001 F= 7.39, df= 1.93 n_p^2=0.10	*p>0.05*	p<0.013 F= 4.53, df= 1.93 n_p^2=0.06
Step Width			
Average	*p>0.05*	*p>0.05*	*p>0.05*
Co-efficient of variation	*p>0.05*	p< 0.001 F= 11.90, df= 1 n_p^2=0.16	*p>0.05*
Step time			
Average	p<0.001 F= 19.13, df= 1.86 n_p^2=0.23	p<0.001 F= 449.07, df= 1 n_p^2=0.88	p= 0.062 F= 2.92, df= 1.86 n_p^2=0.04
Co-efficient of variation	p<0.001 F= 17.3, df= 1.72 n_p^2=0.22	p<0.001 F= 72.71, df= 1 n_p^2=0.54	p<0.001 F= 22.57, df= 1.72 n_p^2=0.57
Swing time			
Co-efficient of variation	*p>0.05*	p<0.001 F= 36.26, df= 1 n_p^2=0.37	*p>0.05*
Single Support Time			
Co-efficient of variation	p= 0.03 F= 3.61, df= 2.00 n_p^2=0.05	p= 0.004 F= 8.93, df= 1 n_p^2=0.12	p<0.001 F= 8.92, df= 2.00 n_p^2=0.12

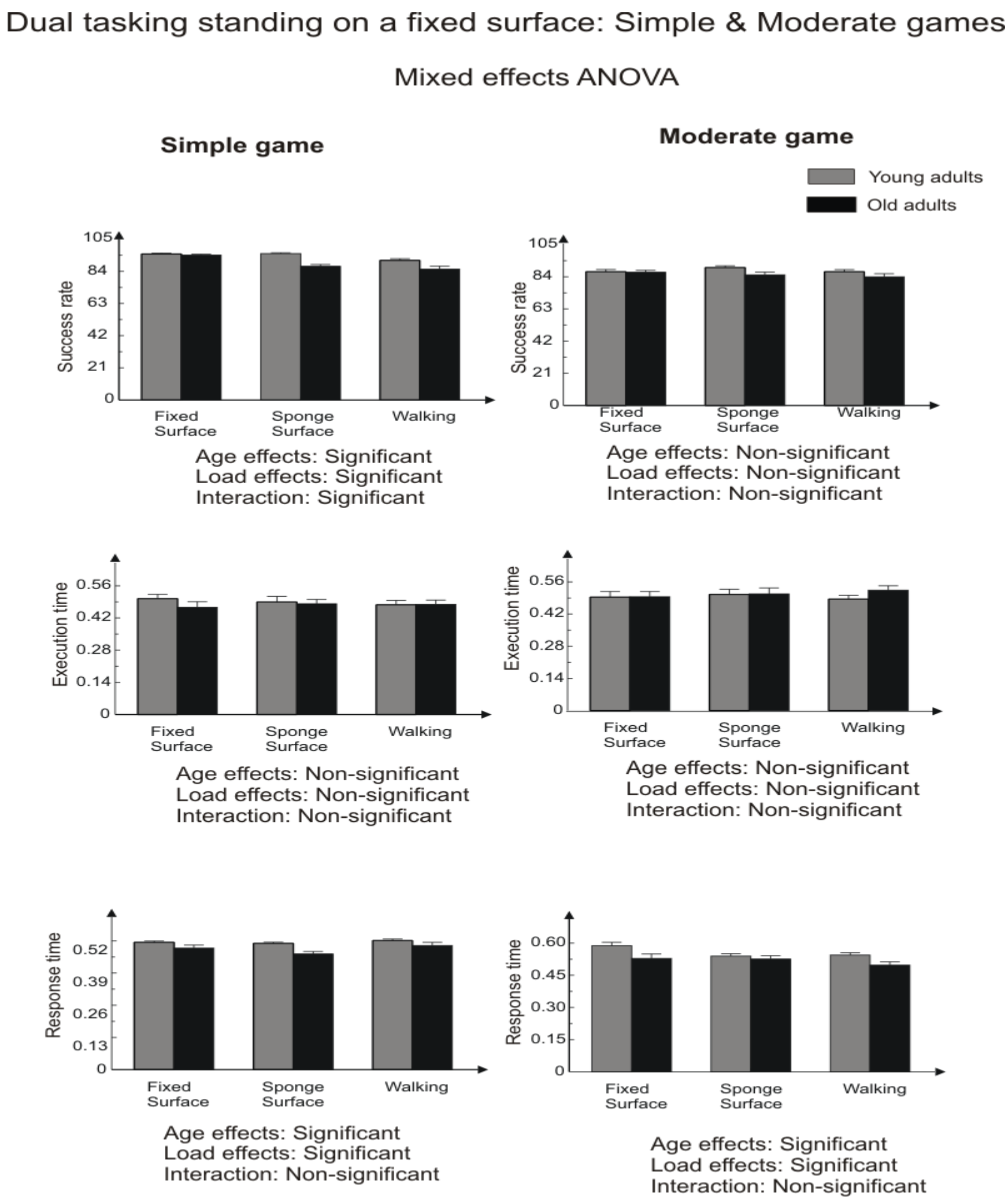
(n_p^2= Effect size) and α= 0.05

5.5.4 Cognitive game performance during different physical loads

Participants played two cognitive games. The first game was a simple game without a distracter while the second game was a moderate game with a distracter. The success rate, execution time and response time while standing on a fixed surface, while standing on a sponge surface and while walking on a treadmill were used as performance indicators.

Figure 26 shows the histograms of the percentage of success rate, response time and execution time while performing the cognitive tasks under different physical loads.

Figure 26: Success rate, response and execution time during cognitive tasks under different physical loads



Tables 11 and 12 show the p values and f statistic of the ANOVAS's performed to find out the age effect, the difference in single task and dual task in young and older adults and the interaction effect while engaging in a cognitive task and standing on different physical loads.

Table 11: Simple cognitive task on different physical loads

Variables	Fixed Surface, Sponge Surface & Walking	Age	Interaction
Success Rate	*p*<0.001 F = 24.45, df= 1.75 n_p^2=0.28	*p*<0.001 F = 23.49, df= 1 n_p^2=0.27	*p*<0.001 F = 8.09, df= 1.75 n_p^2=0.11
Response Time	*p*<0.013 F = 4.51, df= 2.000 n_p^2=0.06	*p*<0.003 F = 9.59, df= 1 n_p^2=0.13	*p>0.05*
Execution time	*p>0.05*	*p>0.05*	*p>0.05*

(n_p^2= Effect size) and α= 0.05

Table 12: Moderate cognitive task on different physical loads

Variables	Fixed Surface, Sponge Surface & Walking	Age	Interaction
Success Rate	*p>0.05*	*p>0.05*	*p>0.05*
Response Time	*p*<0.01 F = 4.17, df= 1.94 n_p^2= 0.06	*p*<0.00 F = 7.95, df= 1 n_p^2= 0.11	*p>0.05*
Execution time	*p>0.05*	*p>0.05*	*p>0.05*

(n_p^2= Effect size) and α= 0.05

Significant dual task effects were observed for both young and older adults during success rate and response time but not for execution time. Both young and older adults demonstrated a better success rate while playing the simple game on a fixed surface than against playing the game while walking on a treadmill. Young adults had a better success rate during sponge standing than while on the fixed surface or while walking. Both young and old adults demonstrated longer response times while playing the simple game and walking on a treadmill. The results also showed a significant age effect with young adults performing significantly better in both success rate and response time when performing the simple game during all three physical load conditions. Execution time did not show a significant age effect during the simple cognitive game. There was an interaction effect observed for success rate but not for response time or execution time.

During the moderate game a dual task effect was observed only during response time and not during success rate or execution time for both young and older adults. A significant age effect was only observed during response time and not during success rate and execution time. There was no interaction effect observed in any of the performance indicators during the moderate game.

5.5.5. Visual tracking performance during different physical loads

The visual tracking task was a closed loop task. The task was performed while participants were standing on a fixed surface, on a sponge surface and while walking on a treadmill at a predetermined speed. As the physical load increased young adults performed better than the older adults. The CoD was used to determine the performance of the visual tasks.

Figure 27 shows the CoD values of both young and older adults while performing the closed loop visual tracking task standing on a fixed surface, sponge surface and walking on a treadmill.

Figure 27: CoD during closed loop visual tracking task

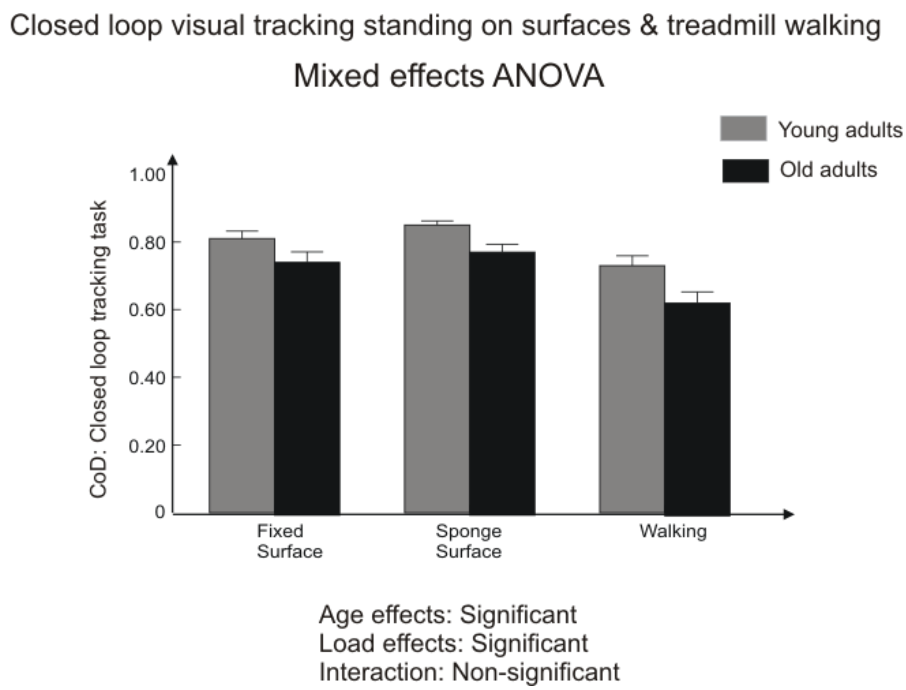


Table 13 shows the results of the two way ANOVA's performed to find out the age effect, the difference between single and dual task conditions in both young and old adults and interaction effect. Younger adults generally performed better in the closed loop task during different physical loads.

The results also showed a significant dual task effect for both young and old adults. Both young and older adults demonstrated a higher CoD while standing on a fixed surface than while standing on a sponge surface or while walking on a treadmill. During the closed loop task, the results showed a significant age effect with young adults performing significantly better than the older adults while standing on a fixed surface, while standing on a sponge surface and while walking on a treadmill. There were no significant interactions observed.

Table 13: CoD of visual tracking on different physical loads

Dual Tasks	Fixed Surface, Sponge Surface and Walking	Age	Interaction
Closed Loop	p<0.001 F = 16.97, df= 1.93 n_p^2=0.21	p= 0. 001 F = 12.55, df= 1 n_p^2=0.17	*p>0.05*

(n_p^2= Effect size) and α= 0.05

Summary of findings during dual task conditions

Younger adults demonstrated better standing balance in the antero-posterior direction and older adults performed better during the medio-lateral direction. This was true during both fixed standing and sponge standing during eyes open, eyes closed, closed loop, simple game and moderate game conditions. During treadmill walking while playing the simple and moderate game, younger adults showed better averages during step length and step time and better co-efficient of variation during step width, step time and swing time. No age effect was seen in co-efficient of variations of step length and single support time and the average of step width. During treadmill walking while performing the closed loop visual tracking task younger adults were better in the average of step length and step time. Younger adults were also better in the co-efficient of variations during step width, step time, swing time and single support time. During the cognitive tasks an age effect was seen only during success rate and response time of the single game and response time of the moderate game in favour of younger adults. This was true in fixed surface, sponge surface and treadmill walking. During the closed loop visual tracking task younger adults performed better in fixed surface, sponge surface and treadmill walking.

Chapter 7: Discussion

Standing balance, walking stability, cognition and visual tracking was compared between healthy young and older adults while they were single and dual tasking on the TRP. The overall objectives of this study were to determine if there was a difference between healthy young and older adults during single task conditions and to determine if there was a within and between group effect during dual tasks.

7.1 Single task conditions

7.1.1 Single task standing balance

The main findings of the study indicate that during single task standing, in general the balance of healthy younger adults was better than that of older adults while standing on both a fixed surface and on a sponge surface.

These results are in line with the results of previous studies. Abrahamov et al and Huxhold et al [9, 23] compared the CoP in both AP and ML directions among young and older adults. In both studies young adults demonstrated better balance than older adults. Another study by Teasdale et al, 1991 [29] compared the postural stability of both young and older adults during normal stance and during altered surface (5cm thick foam). They found that older adults showed significant reduction in balance during the altered surface (5cm sponge surface) but did not find a difference during the control standing (fixed surface). In general, these studies suggest that balance is affected and becomes less as we grow older and more so during challenging surfaces. As the physical load increases in the form of a deforming surface, other sensory systems like proprioception have to come into play to avoid losing balance. This is of significance because we do not always get the chance to walk on controlled flat surfaces. We often encounter different types of surfaces during our day to day life as well as during leisure activities like hiking or trail walking. It is important to note that older adults are prone to falls because of their reduction in balance and appropriate interventions at the right age can reduce falls to a great extent.

7.1.2 Single task walking on a treadmill

The averages of gait variables indicate locomotor pacing or rhythm, while the variability is more representative of walking stability. Both groups did not show major differences during single task walking with respect to the averages. However with respect to variability, younger adults demonstrated reduced stability during the spatial parameters, while older adults showed reduced stability during the temporal parameters. Previous studies have shown that older subjects walked slower than younger during single task [30]. Plummer et al, 2011[31] found differences in gait speed and stride duration variability but no difference during stride duration.

7.1.3 Single task cognition and visual tracking performance while standing on a fixed surface

This study did not find a difference in single task cognition (simple and moderate game) performance between healthy young and old adults while they stood on a fixed surface. However during visual tracking (closed loop) single task, younger adults performed better during the closed loop task.

In general, previous studies [32, 33] did not find a difference during single task cognition performance between healthy young and old adults. The above result with the fact that standing balance was different between young and old adults on the fixed surface indicates that older adults had to compromise on standing stability in order to perform the cognitive game tasks equal to young adults. The closed loop task required the participant to overlap the on screen target cursor with the cursor controlled by the air mouse. It was necessary for the participants to foveate in order to overlap the cursors. It is possible that the ability of older adults to foveate while maintaining standing balance was affected by age.

7.2 Dual task conditions

In our study participants performed the dual tasks by performing a balance or walking task while simultaneously performing a cognitive or visual tracking task.

7.2.1 Balance and dual tasking

Both healthy young and older adults demonstrated better balance during single task standing on a sponge surface, than when they performed a cognitive dual task while standing on the sponge surface. The results that we obtained are in line with several previous studies [34-38]. The CoP has been used to quantify balance in several studies and some studies used postural sway. Our study and a previous study [38] used a sponge to provide the surface based challenge to balance. Other studies have used force plates and platforms that provided perturbation, which is similar to the perturbations that the sponge surface provides. The cognitive dual task was across the spectrum and almost all of the studies used tests that recorded responses in a subjective way. The game based cognitive task and visual tracking task that we used were computer based and the outcome measures are recorded in real time.

Standing balance requires a coordinated effort from the visual, vestibular and proprioceptive system. When participants stand on a sponge surface the proprioceptive system is challenged and balance is affected. The addition of a cognitive task that involves head rotations and visual tracking challenges balance even further. It is but natural that we see a reduced balance performance during dual tasks.

7.2.3 Spatio-temporal gait variables during cognitive and visual tracking tasks.

In general both healthy young and old adults performed better on both spatial and temporal parameters during single task walking than during dual task walking. This was noted more during variability and less in the averages. Between groups, healthy young adults performed better than older adults with respect to both variability and averages. Several studies [21, 24, 26, 30, 32, 39-50] support the results that were obtained in our study. Most of the above mentioned studies that have looked at gait parameters while performing a cognitive task have concluded that there is a reduction in gait speed and increase in variability the moment dual tasks have to be performed. This holds true for both young and older adults. Some of these studies also report that young adults performed better than older adults during dual task conditions.

Literature on the walking element of dual tasking is dominated by over ground walking and in the light of the reduction in speed that has been supported by many studies, we can safely assume that participants reduced their speed and/or prioritized the cognitive task over the gait task. Some studies have used systems called as the Gaitrite [16, 21, 42, 43, 48, 51, and 52] and CAREN system [53]. Others have asked participants to perform over ground walking ranging from 10 meter walk ways to 40 meters. Some asked participants to turn while others did not. A common feature in all of these walks is that participants were allowed to walk at a self-selected speed. This fact makes it difficult to draw valid conclusions because even within a sample participants will be walking at different speeds. These factors also warrant a method that keeps gait speed constant while walking. By keeping gait speed constant for all participants, reliable comparisons can be made during the tasks performed.

Our study used a custom made TRP that has a treadmill which can be used for the walking aspect of the dual task. Other studies [41, 54] have also used treadmill in their dual tasks.

It is also important to discuss the cognitive tasks that were used by these studies to bring about the dual task element. Some of the cognitive tasks that have been used previously were serial 7s and 2s, naming animals, counting backward, enumerating five letter words, naming words that start with a specific alphabet, reciting male and female names, the auditory stroop test and biting a pressure transducer when receiving a stimulus. Most of these tasks are simple and they normally have objective methods of assessing outcomes. It is also difficult to make valid comparisons. Our study utilized a custom made computer based game played under two levels of difficulty. The system automatically gave us information like the success rate, response time and execution time and there is no scope for mistake by outcome assessors. Another task that we did was the computerized visual tracking system. This system gave us the coefficient of determination while performing the visual tracking. Our system is more robust and has also been studied for reliability and validity [55, 56].

Having seen that gait velocity reduces during dual tasks in almost all the studies, it is obvious that participants are slowing down to divide their resources between the gait task and the cognitive task. Task prioritization also plays an important role during dual task performance. Yogev-Seligman, 2010 [46] asked young and old participants to prioritize gait, prioritize cognition task and no specific instruction during dual task walking. Both groups increased their gait speed when they were asked to prioritize gait. This result was in contrast to other studies where gait speed reduced during dual task walking. When asked to prioritize the cognition task, both groups reduced in gait speed like other studies. This clearly suggests both young and older adults are able to prioritize their resources when necessary. Another study that showed how prioritization affects dual tasking was conducted by Verghese et al, 2007 [57] on older adults. When compared to walking while concentrating on both walking and talking, participants were slower than when they were paying attention to only talking.

7.2.4 Cognitive game performance during different physical loads

Both the simple and moderate cognitive tasks that were performed to provide a dual task effect while standing on a sponge surface and while walking on a treadmill produced varying effects in both young and old adults. During the simple cognitive tasks both young and old adults performed consistently better while standing on the sponge surface than when walking on a treadmill. During the moderate cognitive task only one variable showed a difference. While young adults performed better while walking on the treadmill than while standing on the sponge during response time, older adults performed better while standing on the sponge surface than while walking on a treadmill. In general, young adults performed better during the dual tasks when compared to the performance of older adults. One explanation for the varying results is the fact that both simple and moderate cognitive tasks required different cognitive demands. Other studies that have studied the effect of dual task cognition have used a variety of cognition tests. The dual task element in these studies was introduced by asking the participants to walk and perform the cognitive tasks simultaneously, while the single task cognition tests were performed either during controlled standing or sitting.

During two separate studies [42] demonstrated that both young and older adults enumerated significantly fewer figures and animal names during dual task walking than under single task condition. Other authors have found that older adults made less correct calculations [51], slower reaction times [23, 54], lower accuracy [23], and lower verbal fluency [47], lower voice reaction time [58] during dual tasks than during single tasks.

7.2.5 Visual tracking performance during different physical loads

During the visual tracking task young and older adults performed better while standing on a sponge surface than when walking on a treadmill. Both groups performed the visual tracking task better while standing on a sponge surface than during single task visual tracking during fixed standing.

The fact that participants did better on the sponge surface may indicate that participants anticipated the challenge that the sponge surface was going to provide them and adapted their standing balance accordingly. Task prioritization may play a role here as they were not given any specific instructions on which task to concentrate more on. Visual tracking performance (closed loop) has been shown to be decreased during treadmill walking [56].

Chapter 8: Conclusion

The study findings provided evidence for discussion on the effects of single and dual task conditions on balance, spatial and temporal parameters and cognitive function measures in young and older adults.

During walking on a treadmill alone, there was no major difference between both groups. Balance was better in young adults in the AP direction while it was better in older adults in the ML direction. In the cognitive tasks, single task closed loop visual tracking was better in young adults.

The study revealed that there was a strong dual task effect in both young and old adults. Both cognitive and visual tracking tasks and balance and walking was affected as duals tasks were performed. Balance and mobility tasks affected cognitive tasks and the same was true vice versa too. The fact that this was more pronounced in older adults has important clinical relevance.

8.1 Clinical significance

This study has clinical significance because the process of aging brings about changes in mobility and cognition. Many activities of daily living, leisure and employment activities require cooperation between balance and mobility tasks and cognitive abilities. This study has shown that this dual tasking ability is affected even in a healthy older adult population. This gives us the opportunity to identify those who are at a risk and provide appropriate interventions.

8.2 Strengths of the study

1) This study used an instrumentation that was developed to assess both mobility and cognitive tasks while not giving the participant the opportunity to prioritize either of the tasks.
2) The instrumentation use has demonstrated moderate to high reliability for the outcomes used in this study.
3) Unlike several other studies that used over ground walking where participants can reduce their speed and prioritize the cognitive task, the instrumentation used in this study allowed speed to be kept at a comfortable constant speed.
4) The TRP also allowed us to collect any number of steps in a given period of time unlike other studies that had a total of 5 to 8 steps from which the gait analysis was performed.
5) The cognitive tasks assessed in the TRP are computerized and provided objective data on the performance. Previous studies have generally used subjective methods of data collection for cognitive tasks.
6) The whole TRP setup is low cost and can be used even in a clinical setting without costing much.

8.3 Limitations and future suggestions

1) One of the limitations of the study is that the findings could not be generalized overall to young and older adult populations because it included healthy active individuals who regularly visited gyms and fitness classes. Future studies with

older adults who are representative of the generally frail population with co morbidities are needed.

2) Once data on frail and “at risk” of populations are obtained it would be interesting to conduct future research using the TRP as a treatment tool.

Chapter 9: References

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