A Pilot Study: Effect of a Novel Dual-Task Treadmill Walking Program on Balance, Mobility, Gaze and Cognition in Community Dwelling Older Adults

by

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ABSTRACT

A growing body of literature suggests that aging causes restrictions in mobility, gaze, and cognitive functions, increasing the risk of falls and adverse health events. A novel Dual-Task Treadmill walking (DT-TW) program was designed to train balance, gaze, cognition, and gait simultaneously. Eleven healthy community-dwelling older adults (age 70-80 yrs) were recruited to play a variety of computer games while standing on a sponge surface and walking on a treadmill. Data on centre of pressure (COP) excursion for core balance, spatio-temporal gait variability parameters, head tracking performances, and neuropsychological tests were collected pre and post intervention. A significant improvement in balance, gaze, cognition, and gait performance was observed under dual-task conditions. The study thus concludes that DT-TW is a novel intervention program which combines interactive games with exercises to train dual-task abilities in community dwelling older adults.

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DEDICATION

I dedicate my thesis to my parents, Vijay and Anuradha Nayak, and to my twin sister Dipika Nayak, for their unwavering love and support. It is only through their strength that I could persevere through.

Akshata Nayak,

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GLOSSARY OF TERMS

AP: Anterior Posterior

ADL: Activities of Daily Living.

ANOVA: Analysis of Variance

BBS: Berg Balance Scale

COD: Coefficient of determination

COP: Center of Pressure

COV: Coefficient of Variation

CTSIB: Clinical Test of Sensory Interaction and Balance

DGT: Dynamic Gait Index

DLS: Double Limb Support

DT: Dual Task

DT-TW: Dual Task Treadmill Walking

DT-TW: Dual Task Recumbent bicycle

EO: Eyes Open

EC: Eyes Close

FSA: Force Sensory Array

LOB: Loss of Balance

Max-HR: Maximum Heart Rate

ML: Medial lateral

MMSE: Mini Mental Status Examination

MCI: Mild Cognitive Impairment

OR: Odd Ratio

RCT: Randomized Controlled Trial

RMS: Root Mean Square

RR: Rate Ratio

SPSS: Statistical Package of Social science

TMT: Trail Making Test

TRP: Treadmill Rehabilitation Platform

TUG: Time Up and GO

UFOV: Useful Field of View

VR: Virtual Reality

5xSTST: Five times sit to stand test

6MWT: Six Minutes Walking Test

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Introduction

In recent years, it has been observed that aging is associated with restricted mobility, increased risk of falling, and cognitive impairments in older adults (Mirelman et al., 2012; Muir, Gopaul, & Montero Odasso, 2012; van Iersel, Kessels, Bloem, Verbeek, & Olde Rikkert, 2008). Earlier, gait and cognition were thought to be two separate entities. Recent literature indicates that mobility limitations and cognitive impairments coexist (Hirvensalo, Rantanen, & Heikkinen, 2000). For example, reduced levels of executive cognitive function are associated with abnormal gait performance which in turn results in injuries, falls, hospitalization and poor quality of life (de Melo Coelho et al., 2012; Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010).

Many studies indicate that frequent falls and injuries take place while walking and performing a secondary job (Al-Yahya et al., 2011). Dual-tasking is an integration of the goals of two tasks, formed as one unified process. In this regard, a dual-task training program can be one of the best ways of delivering a multi-modal rehabilitation program. To achieve this, treadmills are being merged with different game-based approaches like playing computer games online or virtual reality environments (Feasel, Whitton, Kassler, Brooks, & Lewek, 2011; Mirelman et al., 2012). Such dual-task treadmill programs not only address mobility and cognitive needs, but are also engrossing, fun and interactive. Therefore, it is necessary to develop a cost-effective and easy-to-use intervention program that will make therapy motivating, economical and effective.

Balance and aging:

Balance and stability are two significant elements that are often affected as we grow older. Balance is needed to hold an upright posture, orient the body with regard to the environment, make automatic postural adjustments to keep stability and prevent falls,
which in turn is achieved by the optimum operation of the sensory and motor systems. Balance and stability can be challenged while walking on an uneven surface, negotiating obstacles or manoeuvring in inadequate lighting conditions. These conditions can present a threat to balance and cause falls and injuries leading to mortality and morbidity.

The Sensory Organization Test (SOT) protocol developed by Nashner (1971) identifies abnormalities in the three sensory systems (somatosensory, visual and vestibular) that lead to postural control. During the SOT, useful information delivered to the patient's eyes, feet, and joints was effectively eliminated through calibrated "sway referencing" support surface and/or visual surround, which tilts to directly observe the patient's anteroposterior body sway. By controlling the usefulness of the sensory (visual and proprioceptive) information through sway referencing and/or eyes open/closed conditions, the SOT protocol systematically eliminates useful visual and/or support surface information and creates sensory conflict situations. These conditions isolate vestibular balance control, as well as stress the adaptive reactions of the central neural system (Nashner 1971). In short, patients may display either an inability to make effective use of individual sensory systems, or inappropriate adaptive responses, resulting in the use of inaccurate sense(s).

Cohen et al (1996) recruited 94 healthy community dwelling adults to study the effect of age on balance using SOT conditions. The participants were split into three age groups, i.e. young (30.0±7.7), middle aged (58.1±6.9), old (76.7±2.5), and elderly (83.5±2.9). The results on the number of falls per condition showed significant main effects of age ($p < 0.0001$), and a test condition ($p < 0.0001$), and a significant age by test condition interaction ($p < 0.0001$).Thus showing that older adults had greater falls as their Centre Of Pressure (COP) or body sway measure was higher than that in younger groups.

Whipple et al (1993) used SOT conditions to evaluate the standing balance among healthy adults. He recruited 239 healthy older adults (mean age of 76.5 years) and 34 healthy young adults (mean age 35 years) who walked independently and had no neurological deficits. A significant age effect was observed in conditions 4 (sway stabilized with eyes open), 5 (sway stabilized with eyes closed) and 6 (inaccurate surface movement). Among older adults, 32 % lost balance on condition 5 whereas 52% lost balance on condition 6. Merely 6% and 9% of younger adults lost balance during conditions 5 and 6 respectively. Results indicated that balance was most impaired when both visual and support-surface information were eliminated

Shumway-Cook & Horak, et al (1986) developed a simpler and inexpensive version of the SOT called the Clinical Test of Sensory Interaction and Balance (CTSIB) wherein they used a sponge surface instead of a sway referenced platform, to distort the signals coming from the ground. The foam surface unlike the sway referenced surface, allowed the body to sway in all directions and it also altered the ground reaction force. Grading of CTSIB was done in two ways: 1) Ranking system, that employed a four point ordinal scale: 1- minimal sway, 2- mild sway, 3- moderate sway, and 4- fall and 2) used a stopwatch to record the quantity of time required by the patient to maintain balance to a maximum period of 30 minutes. Several other studies have shown that compared to fixed surface, body sways more on a foam surface (Blackburn, Riemann, Myers, & Lephart, 2003; Creath, Kiemel, Horak, Peterka, & Jeka, 2005; Jeka, Kiemel, Creath, Horak, & Peterka, 2004; Kuo, Speers, Peterka, & Horak, 1998).

Desai et al (2010) evaluated the Dynamic Balance Assessment (DBA) test protocol using the SOT and CTSIB to differentiate fallers from non-fallers in older adults. They recruited 72 older adults' above the age of 65 years and asked them to perform six DBA tests. The tests were as follows: 1) standing with eyes open on a firm surface, 2) standing with eyes closed on a firm surface, 3) viewing visual targets placed 120 degrees apart and performing horizontal head rotation while standing on a firm surface, 4) standing while performing a cyclic arm lifting task, 5) performing cyclic and rhythmical 45 degree horizontal trunk rotations while standing and 6) standing while performing forward and backward trunk bending and then returning to neutral position. These tasks were repeated on a sponge surface. Center of pressure (COP) using a Force Sensory Array (FSA) mat, peak - to- peak excursion and total sway path length in Anterio-Posterior (AP) and Medio-Lateral (ML) directions were recorded. The results showed that loss of balance and COP excursion were more on a sponge surface as compared to the fixed surface ($p< 0.0001$) during eyes closed, trunk rotations and forward and backward trunk bending. The study reported that the scores computed from the 6 tasks were able to distinguish between fallers and non-fallers

Aging, mobility and cognition in older adults:

Both mobility and cognitive abilities are significant components of healthy aging. Mobility and cognitive abilities are closely linked. A fall may be the first indication of an illness related to the effects of aging on mobility.

Antes et al (2013) studied the association between age and falls over one year in older adults (mean age 70.7yrs). They investigated the circumstances and consequences of, and risk factors of falling. The participants were recruited if they had a fall in the last year and a detailed investigation of the fall was conducted. Results indicated that the prevalence of falls was 19% (14.3% for adult males and 21.5% for adult females). Most older adults fell while walking inside their homes (43.2%). The primary reason of falling was stumbling due to irregularities on the ground, lack of attention, and occupied hands among others. Injury was reported by 71% of people who fell, and 14.8% people reported limitations in performing activities after the fall. There was a significant association (in terms of p values and odds ratio) between limitations in performing activities after the occurrence of falls ($p=0.002$, OR: 1.2), fractures ($p<0.01$, OR:5.45), and fear of new falls ($p = 0.03$, OR:2.11).

In a large population based study, it was found that 35% of people above the age of 70 years had gait abnormalities which increased to 46% as the age group went above 85 years (Verghese et al., 2006). Another population based study indicated that 17% of adults aged 65 years and over had cognitive impairments without meeting standards for dementia and 8% had dementia (Graham et al., 1997). Burachio et. al. (2010) showed that motor decline in terms of reduced gait speed accelerates 12 years before any clinical presentation of cognitive impairments.

Callisaya et al. (2010) recruited 412 participants, 235 males (mean age = 72.4 ±7. 0) and 176 females (mean age= 71.6 ±7. 1), to study the association between age and gait variability in healthy older adults. In this study, participants were asked to walk 6 times on a Gait Rite mat (4.6m long) at a preferred speed. On average 27.3 ±5. 4 steps per person were taken into consideration to measure the gait variables (step time, step length, step width and Double Support Time (DST). A weak correlation between old age and gait variability (r = 0.3) was observed. Risk of self reported fall in the past 12 months was associated with greater DST variability (Relative Risk (RR) 1.03), greater step time variability (RR 1.03) and greater step length variability (RR 1.19).

Hoogendam et al. (2014) studied the association between age and cognitive functions. They recruited 3012 healthy older individuals mean age 71.9 years ± 9.7. Cognitive function was measured on the following test batteries: MMSE, Stroop test, Letter-Digit Substitution Task (LDST), verbal fluency test, 15-Word Verbal Learning Test (15-WLT), and Design Organization Test (DOT). Results showed a strong association between age and cognitive function (r = -0.6). For each 10 years gain, there was a substantial reduction in stroop test, LDST, verbal fluency test, and DOT (p<0.01). This indicates that aging strongly affects processing speed and visuo-spatial abilities.

Herman et al. (2010) studied the association between cognitive decline and falls in older adults. They recruited 262 healthy older adults with mean age 76.3 ± 4.3 years and an MMSE score greater than 25. Fall assessment of the previous year was done at baseline, and for the next two years by self reporting. Trail making tests part A and B were used to measure executive cognitive function. Results indicated that people with poorer executive function and no account of falls at baseline were more susceptible to falling over the 2 years (OR: 3.02). Poor executive cognitive function scores were a better predictor of falls. Those with lower executive function experienced 1-2 falls in two years, while those with high executive function experienced only 1 fall in the same point.

Other studies also show a strong association between age and mobility limitations (balance and/or gait), and aging and cognitive decline, both which result in increased fall risk (Buchman, Boyle, Leurgans, Barnes, & Bennett, 2011; Gleason, Gangnon, Fischer, & Mahoney, 2009; Hong, Cho, & Tak, 2010). Thus, suggesting that gait impairments and cognitive declines are significant risk factors for falls.

Effects of aging on dual-task walking performance:

Walking in the community involves complex procedures that involve the continuous integration of optical, tactile and vestibular information. Walking is considered to be an activity which involves executive function and attention, in addition to motor planning and motor performance. The term executive function refers to a group of cognitive actions that include: decision making, planning for public presentation, speed of processing, and inhibiting task-irrelevant information (Bryan & Luszcz, 2000; Jurado & Rosselli, 2007). Daily activities afford numerous situations in which walking must be combined with another task, such as looking out for traffic, using a mobile phone or calling up a shopping list. While doing so, endurance, motor control and executive cognitive functions are tasked with addressing balance threats. Dual-tasking thus poses a bigger challenge among older adults.

Plummer-D'Amato et al. (2011) conducted a dual-task walking study to examine the effect of talking and executive function on gait parameters of 21 Healthy Older Adults (HOA) (74.7 yrs ± 5.9) and 23 Healthy Young Adults (HYA) (22 yrs ± 1.2). Test protocol consisted of 1) walk alone and 2) dual-task- walk while performing a) spontaneous speech (speak in response to a question) and b) auditory stroop (participants had to indicate the pitch of the word spoken). The average gait speed, coefficient of variation (COV) of both stride time and double limb support duration (DLS) were measured while participants walked on a 16m oval track. On average 55 consecutive strides were available for analysis per condition. Results showed that under dual-task walking, there was a significant reduction in average gait speed while talking in both groups ($P<0.05$); however, only the HOA group experienced a significant change in their gait speed ($P<0.001$), stride time variability ($P<0.001$), and DLS variability ($P<0.05$) during the DT auditory stroop task.

Theill et al. (2011) carried a study on 711 (mean age 77.2 ± 6) participants to assess the issue of dual-task walking on gait speed and cognitive function in cognitively healthy and cognitively impaired older adults. Cognitive impairment was defined as a score of less than 25 points on the MMSE. The task protocol consisted of 2 different over ground walking trials (a) walk alone, b) walking while performing a dual-task (1) counting backward from 50 by 2s and (2) walking while enumerating animals (semantic memory). The GaitRite instrumented walkway was used and each walk consisted of 4-5 steps. Average gait speed was calculated. Cognitive functioning in the form of correct calculations and number of animals named were compared as there was no alteration in the number of mistakes and repetitions made during the single and dual-tasks. there was no change in the number of errors and repetitions made during the single and dual tasks. Results indicated that the cognitively impaired group had lower gait velocity under walk alone condition (p<. 001) compared to the cognitively healthy group. Both groups demonstrated a reduced gait velocity under dual-task condition (p<0.001), the between group effect showed that cognitively impaired group has lower gait velocities under working and semantic memory (p<. 001) as compared to cognitively healthy older adults. Both groups decreased in their cognitive performance under dual-task conditions, but the cognitively impaired group performed worse on counting backwards task (p<. 001). A significant interaction was seen between dual-task condition and group (p<. 001). There was no significant change while enumerating animal names.

A study conducted by Muir, Speechley, et al. (2012), studied the effects of cognition and dual-task on gait parameters. They included three groups; a) 22 participants with normal cognition (71 ± 5 yrs), b) 29 with mild cognitive impairment (73.6±6.2 yrs) and C) 23 with Alzheimer’s disease (77.5 ± 5yrs) in the study. The tasks were performed under two conditions a) walk alone and (b) dual-task walking (naming animal, counting backwards from 1's and subtracting 7's from 100’s). The Gait Rite system was used to quantify gait parameters from 4 to 5 steps. The average gait velocity, stride time and coefficient of variation of stride time were used for analysis. Gait parameters for walk alone condition did not differ significantly between the groups. There was a significant decrease in gait velocity (p<. 0001) and increase in gait variability (p<. 003) under dual-task condition for the MCI and AD group compared to the normal cognitive group.

A number of other studies report a significant decrease in gait speed during DT walking independent of age (Al-Yahya et al., 2011; Beauchet et al., 2009; Buracchio, Dodge, Howieson, Wasserman, & Kaye, 2010; Herman et al., 2010; Montero-Odasso et al., 2009; Theill et al., 2011). In this respect it is significant to note that gait speed can determine most of the kinematic and spatio-temporal gait variables. An increase or decrease in gait speed can cause a substantial effect on gait variability. One cannot conclude if the variation in gait parameters is due to the dual-task activity or the gait speed. Hence, data collected while walking at preferred speed cannot be considered reliable

Dual-task training and Aging:

Regular exercise is a route to health and wellbeing. It raises and maintains physical fitness (Globas et al., 2012; Jin, Jiang, Wei, Wang, & Ma, 2012; Nelson et al., 2007). Studies have shown that increase in the level of physical activity improves mobility, balance and reduces the risk of injuries among older adults (Gillespie et al., 2009; Kerse, Butler, Robinson, & Todd, 2004; S R Lord et al., 2003; Robitaille et al., 2005). Also of importance is that there is a strong association between physical activity and executive function (Baker et al., 2010; Middleton, Barnes, Lui, & Yaffe, 2010; Scarmeas et al., 2009; Verdelho et al., 2012).

From the previous section it is clear that dual-task walking results in significant gait changes that have been associated with falls. Dual-task training in older adults have a high potential value to not only train balance but also cognitive functions.

Mirelman et al. (2011) examined the effect of treadmill training (TT) + virtual reality (VR) on 20 patients with Parkinson's disease (mean age 67.1 ± 6.5 years). Training protocol consisted of a virtual reality environment while walking on a treadmill for 6 weeks (3 sessions per week). Participants would walk along the treadmill while viewing a virtual reality environment where they would avoid virtual obstacles while walking. The velocity, size, orientation, frequency of appearance, and anatomy of the virtual objects were changed. Dual-task assessment was done by 1) walking while serial 3 subtractions (DT) and 2) obstacle negotiation (box: 50 cm W×30 cm D× 40 cm H and lines: 50 cm W × 40 cm D apart) on 5-6 steps. Results showed that gait speed improved ($p<0.05$) and variability decreased ($p<. 05$) from pre- to post-intervention. DT cost decreased by 56% following the training program ($p=0. 02$). These preliminary findings suggested that DT training program using VR improved physical performance and reduced fall risks. The limitation of this study is that it did not have a matched control group.

An important goal in every training program is adherence. Adherence can be achieved if the program provides a fun and interactive platform, which not only engages but also motivates the participants to complete the training. Computer games challenge and train different aspects of cognitive executive functions (Kueider, Parisi, Gross, & Rebok, 2012; Nouchi et al., 2012; Oei & Patterson, 2013; Strenziok et al., 2014). Commercial gaming systems such as Nintendo Wii and Microsoft Xbox Kinect require player motion and, in some cases, weight bearing to control game play (Bateni, 2012;

A. L. Betker, Szturm, Moussavi, & Nett, 2006; Clark & Kraemer, 2009; González-Fernández, Gil-Gómez, Alcañiz, Noé, & Colomer, 2010; Taylor, McCormick, Shawis, Impson, & Griffin, 2011). Because of their interactive nature, this approach can be an important tool for rehabilitation as it increases client participation and exercise adherence. At the same time they improve balance and reduce fall risks and injuries (A. L. Betker, Desai, Nett, Kapadia, & Szturm, 2007; A. Betker, Szturm, & Moussavi, 2008; Desai et al., 2010; Feasel et al., 2011; Pichierri, Wolf, Murer, & de Bruin, 2011; T. Szturm, Betker, Moussavi, Desai, & Goodman, 2011).

Szturm et al. (2011)) conducted a study on 30 community dwelling healthy older adults aged between 65- 85 years of age, ambulating independently and having an MMSE score above 24 dividing them into two groups: control group and experimental group to examine the benefits of physical therapy using an interactive video game. The control group had the typical rehabilitation program involving of strengthening and balance exercises while the experimental group received a program of dynamic balance exercises coupled with a computer game, using a pressure mat to record the center of foot pressure (COP). The COP signal was then applied to manipulate the movement and position of the game sprite, in a manner identical to a computer mouse. The program consisted of 16 training sessions of 45 minutes, 2 sessions per week. Computer games were played while the participants stood on a complaint sponge pad. Berg balance scale (BBS), Time Up and Go test (TUG), spatiotemporal gait variables, loss of balance on the sponge surface (LOB- defined as the participant's inability to complete the task due to the need for external support to prevent a fall. A lower composite LOB count is suggestive of greater balance control.) and Activities-specific Balance Confidence Scale (ABC) were the outcome measures. Both groups improved with training, but there was a greater improvement in BBS (P<. 001), LOB counts (P<. 007), and ABC (P<. 02) in the group who received the game-based balance exercise program compared to the control group. Spatiotemporal gait parameters did not indicate any alterations. From this study we conclude that gait performance can be improved by administering programs that involve walking. Exercises done in standing do not have an effect on walking performances.

In a similar approach Bieryla & Dold (2013)) examined the effect of Wii fit training on standing balance control. Twelve healthy older adults (81.5 ± 5.5) were randomly divided into the experimental and the control group. The experimental group completed training using Nintendo's Wii Fit game three times a week for 3 weeks while the control group went on with normal daily activities. There was no difference between the groups at baseline. Results showed significant changes on BBS (P= 0.037) in the experimental group as compared to the control group (p= 0.161).

Anderson-Hanley et al. (2012) conducted an intervention program to study the effect of combining cycling with virtual reality on executive function. 102 older healthy adults were randomized to receive cycling exercise in addition to cognitive task which was presented in a form on an avatar on a screen as a virtual rider (n=38, Mean age 75.7±9.9 years old). Participants has to paddle faster and navigate left and right using the mouse or a touchpad to control their avatar. The control group received cycling exercises only (n=41, mean age 81.6±6.2 years old). TMT (A and B) and Visual Stroop were used to assess speed of processing and response inhibition, respectively. After 3 months, both groups exhibited a change in TMT, Visual Stroop controlling aging and education factor (P< 0.007, 0.05 and 0.03, respectively). The cycling-with-mental-challenges group had a medium effect size of executive function (d=50%), which was greater than the control group. The risk to progress to Mild Cognitive Impairment (MCI) was reduced by 23% when compared to the control group. Though physical performances of both groups improved, the experimental group had improvements on cognitive function as well.

A statement of the problem

Higher rates of morbidity and decline in Activities of Daily Living (ADL) performances are seen as we grow older (Newman et al., 2006). A number of risk factors such as chronic diseases, neurological, musculoskeletal, and cardiovascular declines contribute towards age related declines. These deficits make it difficult to live a normal life (Elble, Thomas, Higgins, & Colliver, 1991; Mills & Barrett, 2001; Winter, Patla, Frank, & Walt, 1990). Studies have demonstrated that poor balance and gait abnormalities with aging results in a diminution in physical activity and an increase in falls.

Walking involves a complex and integrated process of different system.(Angelaki & Cullen, 2008; Chang, Uchanski, & Hullar, 2012; S. R. Lord & Sturnieks, 2005). It is a dual-task process wherein one has to pay attention to the surroundings and walk simultaneously. For example, independent community walking requires balance, motor and cognitive skills, i.e. maintaining balance and simultaneously having cognitive flexibility while navigating through the environment. Lack of attention may cause imbalance and may lead to falls and injuries.

Executive functions are a key aspect of cognition. As we get older, these functions tend to worsen. Decrease in executive function compromises gait and postural stability. There are studies showing stronger associations between abnormal spatio-temporal gait parameters and poorer executive function (Muir, Speechley, et al., 2012; Theill et al., 2011). It has been found that healthy older adults with a cut-off score on the Mini Mental scale have a strong association with falls (Herman et al., 2010). Visual-spatial processing is an important aspect of balance and mobility. While walking in the community, individuals have to process information from the surrounding and the space with respect to their body. Visual-spatial processing increases dual-task costs in older adults as compared to younger adults leading to falls and injuries (Hoogendam et al., 2014; Nagamatsu, Liu-Ambrose, Carolan, & Handy, 2009) because balance and cognition decline in older adults.

A number of studies report that age has an effect on balance, mobility and cognition (Antes et al., 2013; Callisaya et al., 2010; Herman et al., 2010; Hoogendam et al., 2014). Moderate degrees of physical activity (PA) help in improving balance and mobility skills in the elderly along with increasing range of motion, intensity level, cardiovascular fitness, gait velocity and endurance (Colcombe et al., 2004; Keysor & Jette, 2001). Regular PA, can reduce morbidity, postpone disability and prolong independent living(Christmas & Andersen, 2000). Hence, it is really important to design a program that trains balance, mobility and cognition simultaneously. These programs will motivate people with cognitive decline and balance dysfunction to complete long-term and tedious rehabilitation regimens.

Recent studies show that games–based exercise programs done in a standing position do not induce an effect on walking performances (Bieryla & Dold, 2013; T. Szturm et al., 2011). Therefore, dual-task exercise program that can translate the learnt effects from the training into daily lives can have a substantial effect on older adults. For example, virtual reality (VR) environments viewed during treadmill walking have recently been used to provide a more task-orientated approach to mobility training (Mirelman et al., 2011).

For this purpose, a pilot study was conducted to examine the effects of a dual-task game-based exercise training program on healthy community dwelling older adults.

Study Objectives

The primary objectives :

a) To study the effect of a dual-task treadmill walking program (DT-TW) on balance, gait, gaze and cognition.
b) To determine the acceptability of the study design and process, procedures, resources and management(Thabane et al., 2010) as well as estimate the participant's retention and exercise compliance rates in this novel feasibility study.
c) To explore the "lived experiences" of the study participants who finished their respective exercise programs. The extensive research questions are “What were the experiences of the study participants with the dual-task treadmill

walking (DT-TW) programs and on what context were the experiences based upon?”

Hypotheses:

1. DT-TW exercise program will improve core balance (reduction in centre of pressure excursion) and gait (decrease in spatio-temporal gait variability) performances.
2. Executive function like processing speed, reaction time, visual search, mental flexibility, task shifting will improve post DT-TW intervention.
3. Dual-task exercise programs will improve gaze (smooth pursuit and Visuo-occular reflex) stability post-DT-TW intervention.

Ethics Approval:

The study protocol has been approved by the Human Research Ethics Board (HREB) (Reference number: H2013:293) Bannatyne Campus; University of Manitoba.

Method:

Study design:

This study is a part of a randomized controlled trial (RCT) .The qualitative and quantitative data of the randomized controlled trial (RCT) were collected and analyzed by a mixed method design. This thesis only reports the results of the experimental group. Hence, can be considered as a single arm study.

Sample size:

Eleven healthy older adults.

Inclusion criteria:

- Age between 70-80 years old.
- Living in community.
- Community ambulant: participants can walk 400 meters without assistive devices outdoors.
- Fell only once in the previous year
- Adequate vision and hearing (self reported by the participants)
- Speak English
- The Mini Mental Score Examination (MMSE) ≥ 25

Exclusion Criteria:

- Self-reported diagnosis or history of (i) stroke, traumatic brain injury or other neurological disorders such as Parkinson's disease and Vestibular disorders., (ii) cardiac disease who did not receive clearance from their physician to take part, and iii) muscular-skeletal injuries or orthopedic diseases such as acute lower back or lower extremity pain, peripheral neuropathy, advanced hip/knee arthritis.
- Any recent medical illness that would affect their balance or ability to walk for a period of at least 6 minutes.
- Participants with cardiac disease who a) have not completed cardiac rehab;

b) Are less than six months past the completion of cardiac rehab.

Recruitment:

The staff at the Reh-Fit Centre helped in recruiting the clients by providing a brief overview of the study to the clients at the Reh-Fit center. Also, the research study advertisement was posted in the Reh-Fit center with a brief description about the study.

Randomization:

Participants were assessed by a blind assessors prior to starting the intervention and within one week of finishing the eight week program. A this study is a part of a RCT, the participants were randomly assigned to the dual-task treadmill training (experimental group) or the dual-task recumbent cycle (control group) group by opening an opaque envelope which was enclosed by a code number. The experimental group was assigned code one and the control group code two. The blind assessor handed the envelope to the participants after the completion of the assessment. The envelope was opened in the presence of the blind assessor and the investigator by the participant. Once assigned to the group, the investigator called the participants and schedule appointments for the training sessions.

Instruments and recording

1. Standing FSA pressure mapping system (Vista Medical, Ltd, Winnipeg, Canada): These flexible thin mats (2mm thick) with a sampling frequency of 30 Hz were placed on a fixed floor surface, or a compliant sponge surface to compute the vertical center of the foot pressure (COP) excursion in the AP and

ML directions for all tasks. The mat has a configuration of 256 piezo-resistive sensors (16 of 16) and each sensor covered an area of 2.8 cm^2 (for more details see Desai et al. 2010).

2. Treadmill (SportsArt Fitness Ltd) with a Force Sensory Array (FSA) pressure mapping mat: A treadmill with hand rails and an overhead harness to provide safety while performing the tasks was used. Underneath the treadmill belt a Force Sensory Array (FSA) pressure mapping mat (Vista Medical Ltd., Winnipeg, Canada) with a sampling frequency rate 60 Hz was embedded in thick Teflon. It had 512 pressure sensors (16 of 32) each 2.8 cm^2, which record vertical ground reaction forces and the following spatial and temporal gait variables for each step: a) step length b) step width; c) foot location in ML direction; d) cycle time; e) swing time and f) single support time (Tony Szturm et al., 2013). Treadmill walking was a beneficial option for the following reasons: a) control walking speed "consistency"; b) provided us with 60 consecutive steps within one minute; c) increased safety as it had handrails to prevent any unexpected injuries among elderly with mobility limitations (for a detailed description see Szturm et al. 2013).
3. Adapted Game controller: A commercial, “plug-n-play” head tracking computer mouse (Gyration In-Air mouse, SMK-Link USA, cost $75.00) (Shih, Chang, & Shih, 2010) was used for evaluating and training the participants. This mouse attached to a headband and was secured with a Velcro which allowed the participants to move their head (left-right and/or up-down). The movement-sensing mouse was set up with a small gyroscope and accelerometer sensors

which derived angular displacement signals. The on-screen cursor movement was synchronized with the motion signal derived from the mouse motion. With this simple method, seamless and responsive hands-free interaction with was made possible (Lockery, Peters, Ramanna, Shay, & Szturm, 2011; T. Szturm et al., 2011; Tony Szturm et al., 2013).

Interactive computer game applications: a) A custom computer application was used for testing purposes. This game application was developed by Szturm and his colleagues (T. Szturm et al., 2011; Tony Szturm et al., 2013). For training purposes we used commercial online games called Big Fish Games (http://www.bigfishgames.com).

We selected a few games from this website that targeted executive cognitive functions like speed of processing, cognitive inhibition, working memory and visual search. Following games were played by the participants: “Action Ball”, “Aquaball”, "Abundante", “Bejewelled” “Birds Town”, "Butterfly Escape", “Brave Piglet”, “Jet Jumper”, and “Feeding Frenzy”. The games were divided in three categories; 1) slow, 2) medium and 3) high. The progression depended on how well the participant performed.

Outcome measures and Data Analysis

The accompanying data will be gathered at baseline prior to commence of the intervention:

1. Age

2. Sex
3. Fall history in the past 12 months
4. History of disease/injury process
5. Current medications.

Primary outcomes

Core balance:

The participants performed the following tasks: a) eyes open (EO); b) eyes close (EC); c) a visual tracking task (described below); d) visual spatial cognitive tasks (simple and moderate) (described below). The tasks were performed in standing on a fixed and a sponge surface (50.8 cm x 50.8 cm x 10.16 cm) for 45 s.The participants were asked to stand on a treadmill in front of a 80cm TV screen which was kept at a distance of 100cm. The treadmill had handrails and an overhead support system for safety. Average Root Mean Square (RMS) and Peak-to-Peak amplitudes were computed from the Anterior posterior (AP) and Medial lateral (ML) COP (center of pressure) excursions. Increase in COP excursion is indicative of decline in stability (Abrahamová & Hlavacka, 2008; Blackburn et al., 2003; Desai et al., 2010; Jeka et al., 2004; Patel et al., 2008; Shumway-Cook & Horak, 1986; T. Szturm et al., 2011).(Figure1,

Figure ***3*** - Centre Of Pressure (COP) excursion on Sponge Surface

and).

Gait performance:

Each participant was asked to walk for two minutes at a fixed speed of 0.9 meters per second. Average and coefficient of variation (COV) of spatio-temporal gait variables were computed from 50 steps. Spatio-temporal gait variables consisted of : single support time (the amount of time the foot is on ground), swing time (the amount of time the foot is not in contact with the ground), cycle time (the time taken by one foot from its initial contact of the cycle to the next initial contact of the next gait cycle), step length (the distance between the points of contact of one foot to the same point of contact with the other foot) and step width (the side to side distance between the feet) and foot location in ML (variation). Steady and rhythmic gait (lesser variability) is indicative of no gait impairments (Ihlen et al., 2012; S. Lord, Howe, Greenland, Simpson, & Rochester, 2011) (Figure1).

All the dependent variables were computed using MATLAB scripts (The MathWorks, Natick, MA, version 2010) that were written in our lab.

Head Tracking Performance Measures:

The head tracking performance measure consisted of tracking a bright visual target that moved left and right (horizontally) on the screen in a sinusoidal fashion for several cycles. It was developed in the lab for testing Dynamic Visual Acuity. The closed loop task was selected for this study in which a computer generated reference target was to be tracked by a cursor that the participant had to move by moving his/her head left and right using a head-mounted motion mouse (Gyration, SMK-LINK Electronics, and USA) which was secured by a Velcro on a head band (Appendix 1). The target cursor moved at a predetermined frequency of 0.5 Hz with an amplitude of 60% of the monitor width. 30-40 degrees of horizontal head rotation to the left and right side of the monitor from the centre was achieved. At a frequency of 0.5 Hz, an average head rotation velocity of 60 °/s and a peak velocity of 80°/s , the smooth pursuit system was stimulated (Tony Szturm, Reimer, & Hochman, 2015). The participants had to foveate to overlap the cursors over the target which required smooth pursuit and vestibular function to coordinate the eye and head motion.

Participants were asked to perform this task for 45 seconds while standing on a fixed and a compliant sponge surfaces (single task) as well as walking at 0.9 m/s (dual-task). Gaze performance was computed using the coordinates of the data and time intervals of each event of the reference signal (computer reference target) and the user movement (head rotation). Coefficient of Determination (COD) (a non-linear least squares algorithm to extract the variables) was used to quantify the head tracking data i.e. the sinusoidal movements of the user's head rotation with respect to the computer "reference" signal. The COD was computed by the total and average residual difference between the user's and the computer signals. Thus, an excellent gaze performance was achieved if the two cursors overlapped perfectly. The first two cycles of the tracking tasks were excluded in order to allow the participant to adjust and begin tracking ().

Cognitive game Performance Measures:

A validated and modified version of the Useful Field of View test (UFOV) was used to examine both visual-spatial processing coupled with eye-head coordination and the ability to select relevant information and ignore irrelevant information (cognitive inhibition) (Lockery et al., 2011; T. Szturm et al., 2011; Tony Szturm et al., 2013). Two test games were used 1) a simple test game in which the participant had to move the game sprite (paddle) to catch bright circles (targets) that fell vertically from top to while simultaneously avoiding distracting objects of different shapes and colors and 2) a moderate test game in which the participant had to play the same game but this time with the distracters falling diagonally. The objects appeared at a fixed interval of two seconds at random locations on the monitor. These games (simple and moderate) were played while standing on a fixed surface, sponge surface and while walking on the treadmill at 0.9m/s for 60s. The signals generated from the player performance with respect to the game events were recorded to create a file. The coordinates of the file depended on: a) time index and coordinates of each game object; b) position coordinates of the game paddle in respect to head rotation.

The following variables were quantified: a) game success rate (percentage of targets that are caught), b) average motor response time (time from appearance of the target to start of the paddle movement) and c) average movement excursion time (the time from beginning of the movement to the final location (plateau). The games were played for 60s and each game event was 2 seconds in length resulting in recording a total of 60 game events. The game recording began at the time when the target appeared and hit the paddle due to player movement. At time zero, the target appeared at the top of the screen (event onset), and the event ended when the target was either hit by the paddle or disappeared as the player missed the target (Lockery et al., 2011; Tony Szturm et al., 2013) (Figure 5).

Neuropsychological tests include:

The Mini Mental Score Examination (MMSE) test is the most widely used screening tool for detection of cognitive deterioration in older adults. The MMSE is a 20-item instrument that is utilized to screen five areas of cognitive functions: orientation, visual spatial abilities, attention and calculation, recall and language. MMSE scores range from 0 to 30 points. Lower scores indicate greater degrees of general cognitive dysfunction. The possible maximum score of the MMSE is 30 points (Folstein, Folstein, & McHugh, 1975).

Trail Making test (A & B):

The Trail Making Test (A and B) is a valid and reliable well-established test measure to target mental flexibility, visio-spatial skills and task-switching. This test is widely used and is graded by time (IJmker & Lamoth, 2012; McGough et al., 2011; Mirelman et al., 2012; Montero-Odasso et al., 2009). It is administered in two parts which are: 1) Trail Making test TMT form A (90 seconds), in which the subject is required to draw lines sequentially connecting numbered circles (1,2,3,4,..) arranged randomly on a page as quickly as possible; 2) TMT form B (3 minutes) is a more demanding task as it requires the subject to connect circles containing numbers and letters in an alternating sequence (1,A,2,B,3,C,....). The participants had to complete the task within 3 minutes. Time taken to complete the test and number of errors are recorded.

Verbal fluency:

Verbal fluency is a test of memory recall in which the participant had to enumerate as many words as possible from the letters "F", "A" and "S". They also had to enumerate names of animals. The time for each task was 60 seconds. The test has been shown to be highly reliable and valid among elderly population (Henry & Crawford, 2004; IJmker & Lamoth, 2012; Passos et al., 2011).

Visual search test:

The visual search test is a test of speed of processing and cognitive inhibition. The participant had to choose the target amongst other distracters. The test measured both reaction time and the number of selected items. They had to complete the test in 60s. It has been shown to be reliable and valid measure among the elderly (Innes, Jones, Anderson, Hollobon, & Dalrymple-Alford, 2009; Wolfe, 2001)

Pre and post intervention will be spread over two day each lasting 90 minutes with ample rest periods in between and the assessment will be done by a blind assessor. An overhead safety harness will be secured to a support system, and the treadmill has hand rails, as participants may lose their balance while performing a dual-task activity. Also during all tests, a Physical Therapist will stand behind or beside the participants to provide assistance if required.

Secondary outcomes

Five-Time Sit-to-Stand Test:

Five times sit to stand assesses functional lower extremity strength, transitional movements, balance, and fall risk. Participants were asked to stand up and sit down five times with both arms folded across the chest and time was recorded (Goldberg, Chavis, Watkins, & Wilson, 2012)

Walking capacity/endurance 6-minute walk test:

Participants were asked to walk on the track of the Reh-Fit Center for six minutes and the distance was recorded (Abrahamová & Hlavacka, 2008).

Assessment Protocol:

A consent form was signed on the first visit which was followed by the assessments. Assessments were conducted in two days before and within one week after the completion of the intervention. Day one of the assessment consisted of clinical, functional tests: a) six minute walk test (6MWT); b) five times sit to stand test; c) standing on fixed and compliant sponge surface with eyes open (EO) and eyes closed (EC) for 45 seconds; as per CTSIB (Clinical Test of Sensory Interaction and Balance). Day 2 consisted of a) Participants walking on a treadmill and performing computer-based therapeutic games (The Treadmill Rehabilitation Platform (TRP) test protocol) which measured spatio-temporal gait parameters under dual task conditions. Treadmill had hand rails and an overhead body support system for safety). b) Neuropsychological tests like Trail Making Test part (A & B); b) visual search; c) verbal fluency.

The TRP test protocol was first done while standing on a fixed surface followed by standing on the sponge surface which was then progressed to walking on the treadmill at a speed of 0.9m/s while playing head tracking and cognitive game tasks. Head tracking (smooth pursuit and vestibular function) was played for 45 seconds and required eye and head movement coordination. Cognitive game tasks was played for 60 seconds each and required visuo-spatial processing (simple and moderate; 60 minutes apiece).

Intervention Protocol:

Each participant received a 45 minute dual-task training program twice a week for 8 weeks.

Dual-task Treadmill walking (DT-TW) training program protocol consisted of:

Ten minute core balance training was provided by asking the participants to play different cognitive games while standing on a sponge. To increase the balance cost, an air bladder to train core balance was incorporated in the training once the participant got better on the sponge surface. Thirty- five minutes of dual-task treadmill walking while viewing moving objects or words on a computer monitor, and performing various tasks similar to playing brain fitness or cognitive games. Participants played 5-6 different Big Fish games (www.bigfishgames.com) which trained different aspects of executive cognitive functions (Appendix 2).

To increase the balance cost, an increase in the treadmill speed was incorporated in the training once the participant got better in the task. Rest periods were provided as required. The initial starting speed for all the participants was 1.0 m/s. The velocity was gradually increased depending the participant's level of comfort.

Dual-task Treadmill Recumbent Cycling program (DT- RC) Protocol

This study is a part of a bigger RCT study in which a control group training program was conducted by Rehab Alhasani (graduate student, Medical rehabilitation) who recruited 11 participants for the study. One group received the dual-task treadmill walking program (DT-TW) and the second group received the dual-task recumbent bicycle program (DT-TW). Both training programs contained the same cognitive activities delivered through interactive "cognitive" video games. This dual-task recumbent cycling training plan targeted cardiac fitness, gaze control and an improvement in cognitive abilities while cycling and playing different interactive computer games. The protocol of this study included 10 minutes of warm up and cools down, followed by 35 minutes of dual-task recumbent cycle (DT-RC) training. Pedaling speed and resistance was selected to achieve a moderate heart rate intensity of 40% to 60% of maximum. The Max-HR was computed by applying the formula (220-age) with a goal of maintaining 70-90 revolutions per min (RPM)(Cruise et al., 2011; Tanaka et al., 2009). The rate was selected as it has been established as the most efficient pedaling rate for long distance cyclists (Hagberg, Mullin, Giese, & Spitznagel, 1981). Rest periods were provided as required. The cycling speed will be based on Target Heart Rate (THR) set by therapists. Heart rate (HR), blood pressure (BP), revolutions per minute (RPM) and the rate of perceived exertion (Per the Borg 1-10 scale) were also recorded. The protocol for this study was published in 2015 (Alhasani et al., 2015).

Qualitative analysis:

A 30 minute individual interview was conducted once the DT-TW training was completed. Open ended questions were asked to the participants to understand their lived experiences about the program (Kvale, 1996). The interviews were conducted individually by the examiner and the blind assessor. The interviews were conducted based on two predetermined themes : 1) Experience in terms of the intervention and 2) Experience in daily activities. These themes helped in generating specific questions such as: 1) Was the exercise program was appropriate, flexible, and achievable? ; 2) Were the cognitive games engaging and motivating?; 3) perceived exercise benefits; 4) perceived difficulties with the exercises and using the technologies; 5) Recommendation and comments for improving the exercise program. Questions were asked by the examiner and notes were taken by the blind assessor which were then interpreted and reported as a textural description (Appendix 3). Any comments that did not fit in the main themes were reported as comments from the participants. The aim of the interview was to gain insight on what the participants experienced during the DT-TW program. The qualitative approach was based on the phenomenological methodology design (M. Z. Cohen, Kahn, & Steeves, 2000; Crabtree, Miller, & Swenson, 1995; Creswell, 1998; Johnson, 1995; Moustakas, 1994).

As this study is a part of a larger Randomized Control Trial (RCT), the qualitative analysis in this study was designed based on the qualitative analysis for the RCT.

Statistical Analysis

Demographic variables at baseline were computed by Mean and standard deviation values of age, MMSE, 5 times sit to stand test, speed of walking over 25 meters and distance walked in 6 MWT. Ratio was used to compute sex.

Paired t-test was used to compare the means of the effect of DT-TW on the following parameters:

- Spatio-temporal gait variables: The average and COV of
  - Spatial (Step length, Step width and foot location ML)
  - Temporal (Swing time, single support time and cycle time)
- Core balance: RMS and Peak to Peak amplitude COP excursion
- Head tracking: COD (total and average of the residual error differences of user signal in comparison to the reference signal).
- Cognitive game data:
  - Average success rate;
  - Average response time;
  - Average execution time;
  - Average movement efficiency;
- 6 Minute walk test: Distance covered
- speed: time taken to walk to walk 25 meters
- Neuropsychological tests
  - TMT part A and part B
  - Verbal fluency: Correct responses

- Visual search: Correct responses

- Cognitive Game:
  - Average success rate;
  - Average response time;
  - Average execution time;
  - Average movement efficiency;
- Visual Tracking: COD (total and average of the residual error differences of user signal in comparison to the reference signal).

The analysis was be performed using Statistical Package for Social Science (SPSS) software for windows, version 22.0 (SPSS Inc. Chicago, IL, USA) with a significance set at $p \leq 0.05$ (two-tailed). Bonferroni corrections ($p < 0.01$) for multiple comparisons were used. The qualitative data was analyzed by using a content analysis approach (Hsieh & Shannon, 2005).

Repeated measure of analysis of variance (ANOVA) will be used to analysis the data outcomes between the experimental (DT-TW) and the control (DT-RC) groups. The within group factor will be the time (pre-treatment versus post-treatment) the between group factor will be the treatment (DT-TW versus DT-RC).

Figures:

Figure 1 - Snapshot of Treadmill and Standing Mat data recording and analysis: FSA: Force Sensory Array; COP: Centre of Pressure

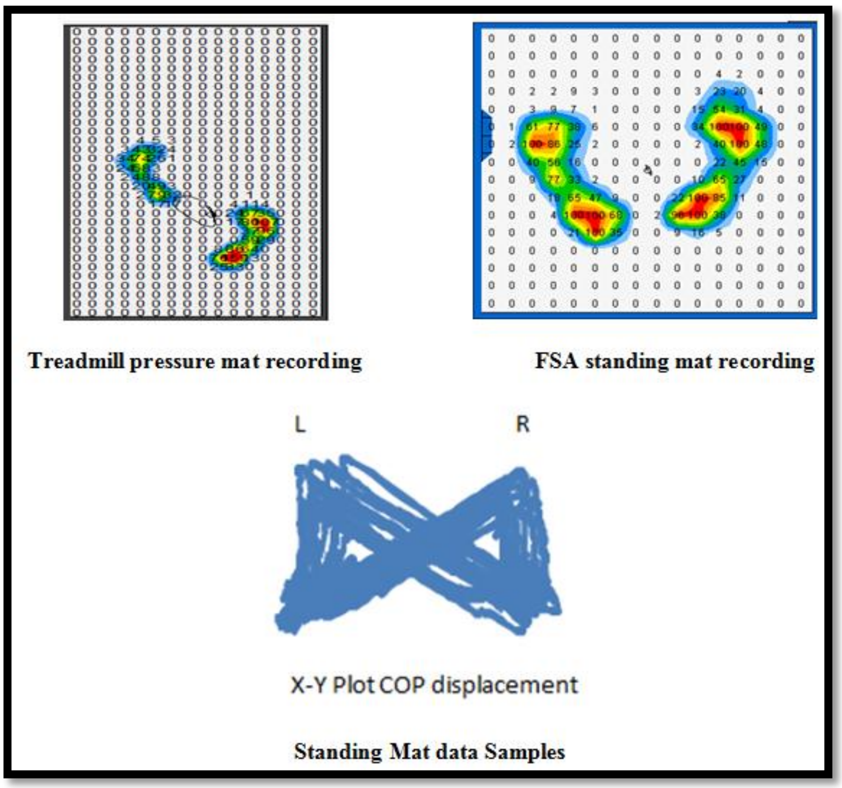


Figure 2 - COP excursion on Fixed Surface

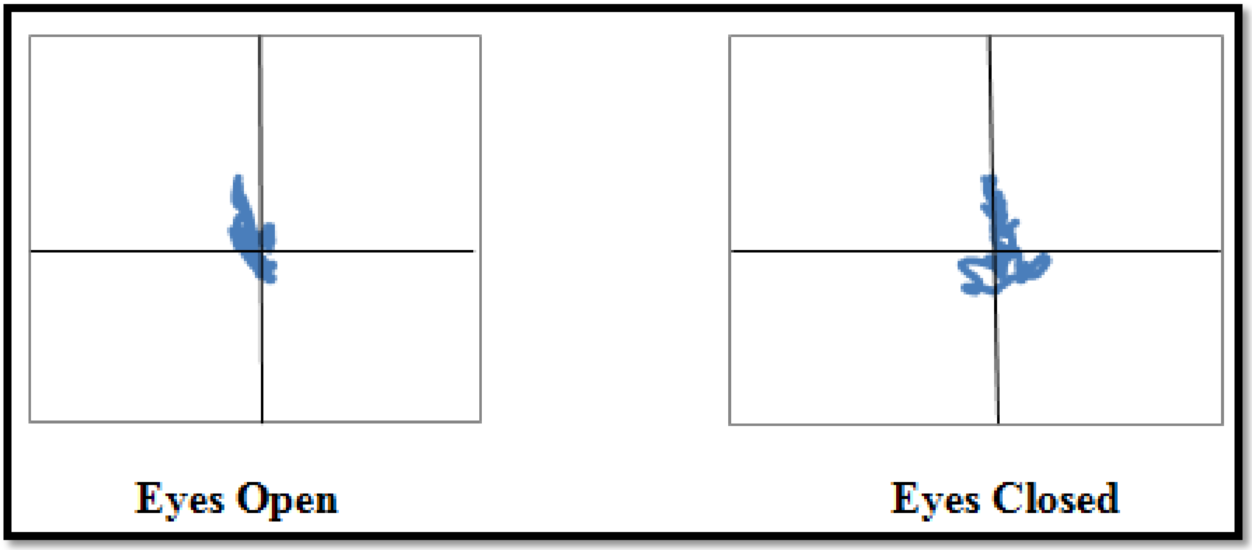


Figure 3 - Centre Of Pressure (COP) excursion on Sponge Surface

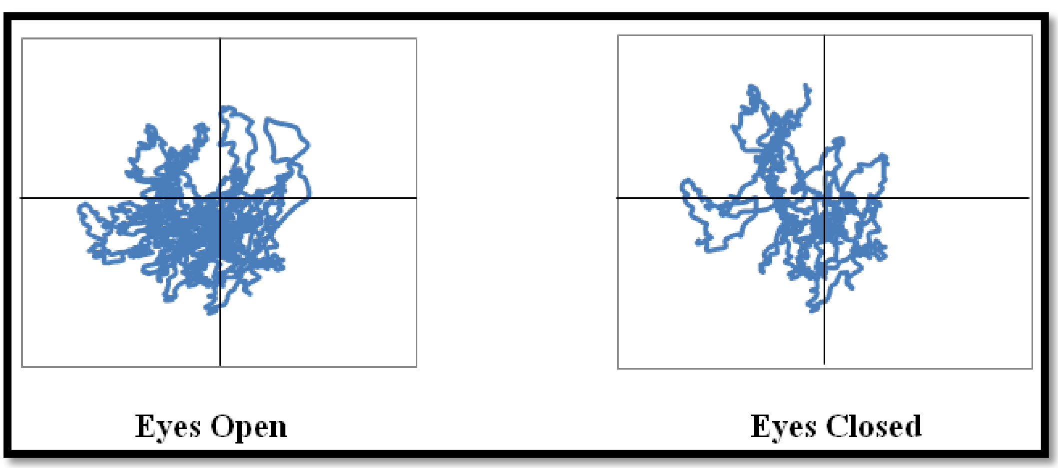


Figure 4 - Head Tracking Data

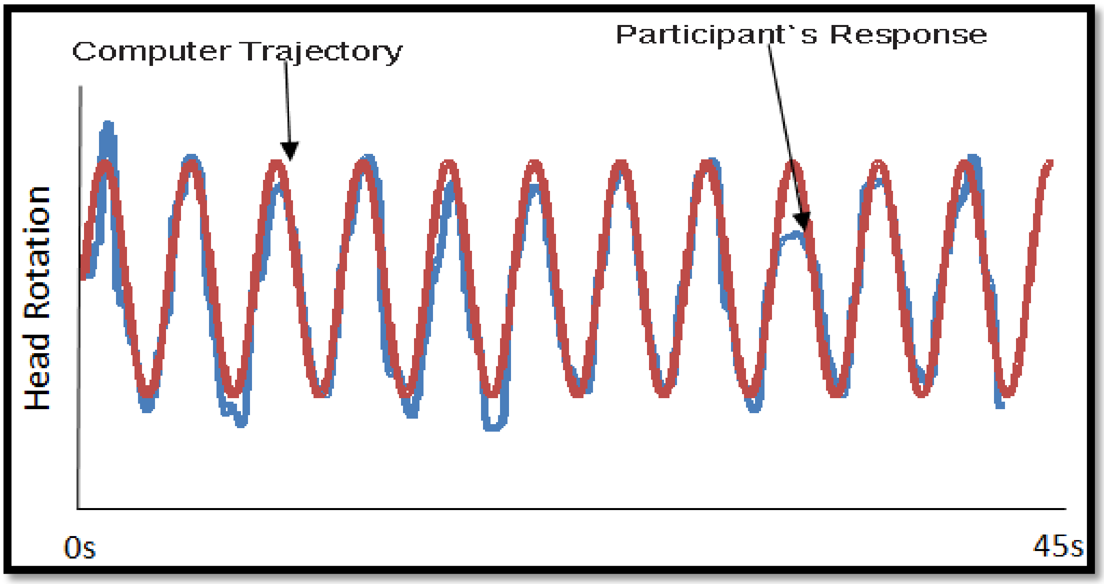
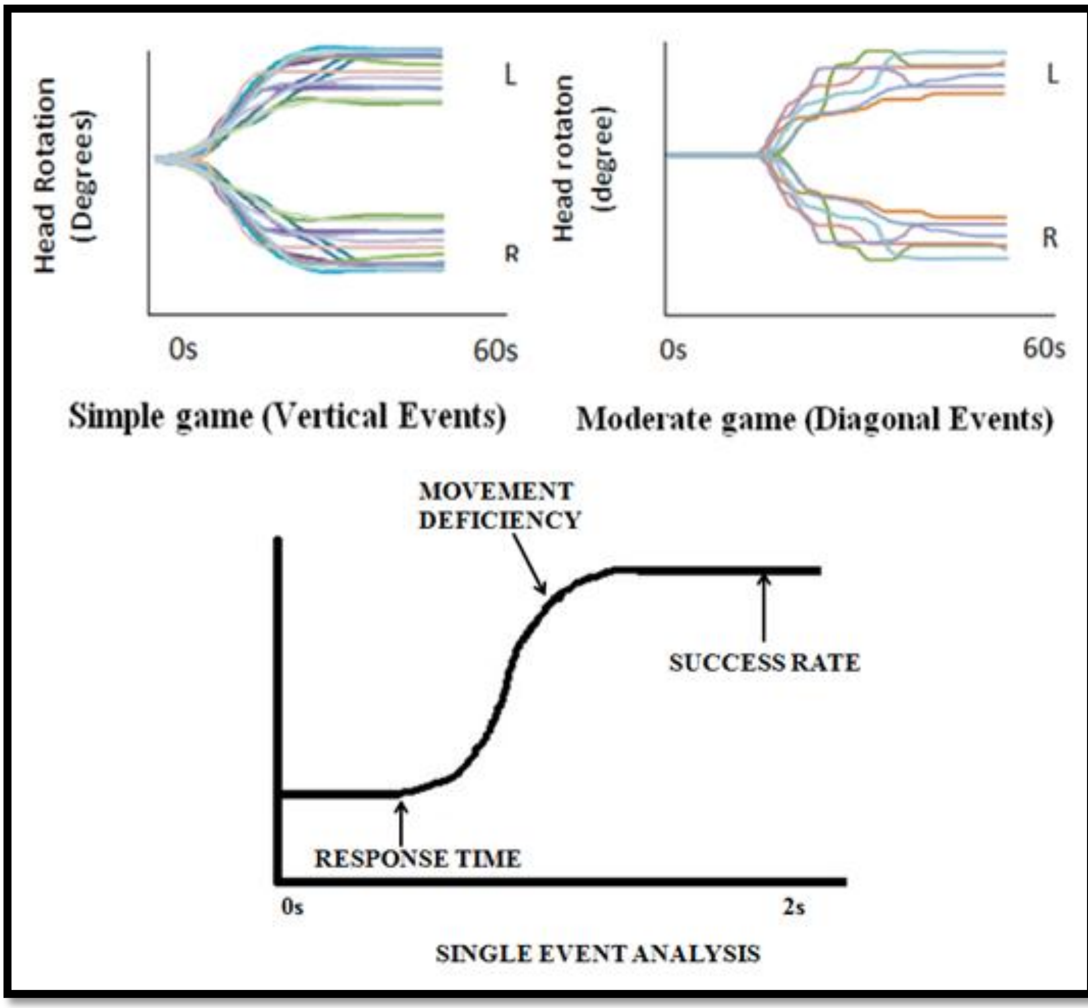


Figure 5 **-** Sorted Episodic gaze with one distractor



Result

Eleven healthy older adults (Six males and 5 females) aged between 70-80 years were recruited at the Reh-fit center for this program. Table 1 -represents the means and standard deviations (SD) for the demographic data. As all the participants had faster speeds, speed was measured by completing a 25 m walk.

Table 1 - The means and standard deviations for the demographic data

Baseline Characteristics	Mean(SD)
Age (years)	75.5 (3.1)
Gender ratio (Males: Females)	6:5
MMSE	28.7 (1.0)
Speed (m/s)	1.8(0.1)
Distance (215.16 m./lap)	584.2(48.9)
5xSTST (second)	10.18(2.5)

Process Evaluation

All participants underwent a baseline and a post assessment after completing the dual-task treadmill walking (DT-TW) training program. 100% attendance and retention rate was achieved after the training sessions. No adverse events were reported.

14 volunteered for the program out of which three participants dropped out of the program after the initial assessment i.e. before the commencement of the training. The results interpreted below are based on the 11 participants who completed the program.

Quantitative analysis:

Effect of dual-task treadmill walking training program (DT-TW) on Standing balance (Stability)

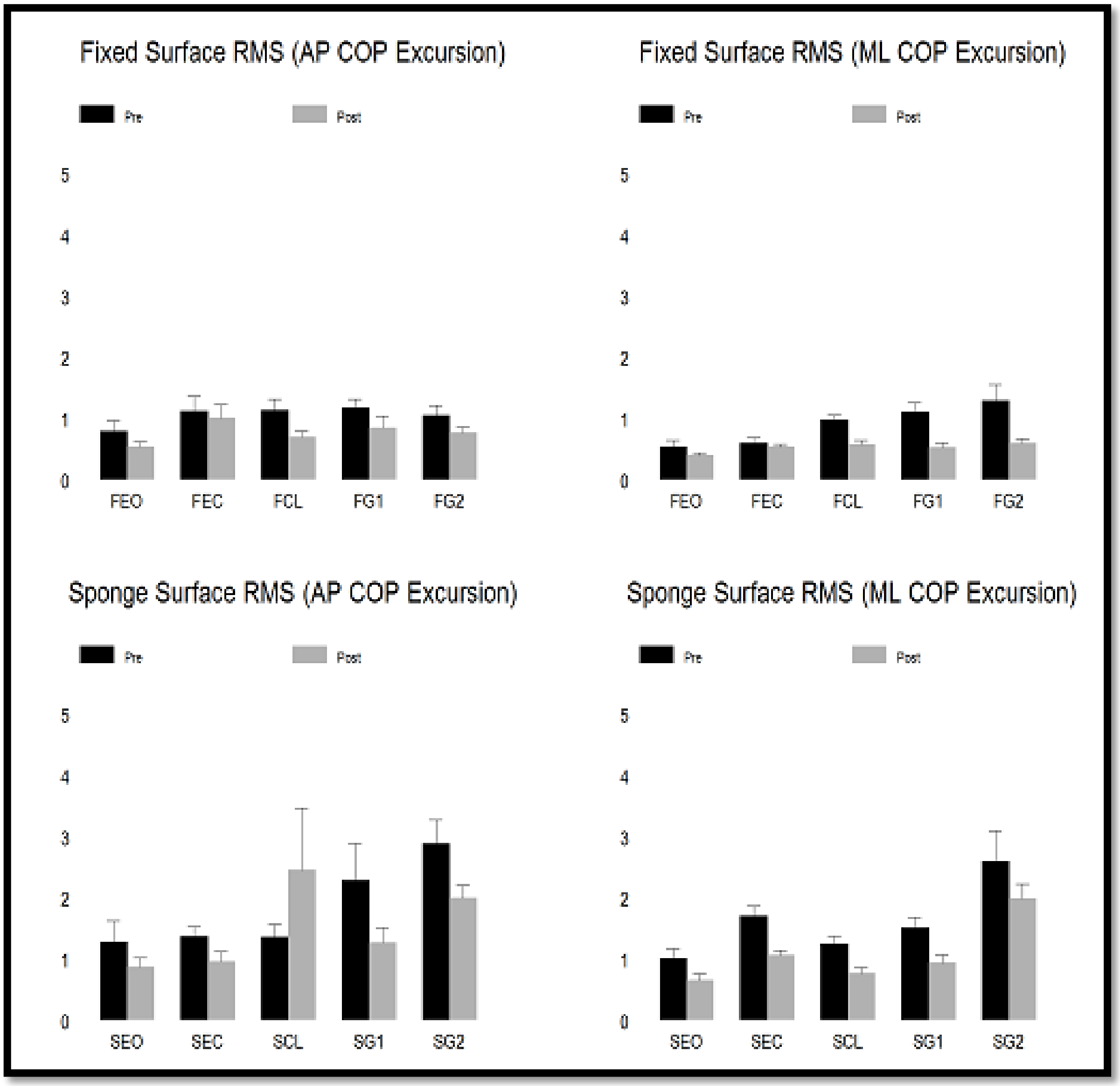
Root mean square (RMS) and peak-to-peak amplitude Center of Pressure (COP) excursion in anterio-posterior (AP) and medio-lateral (ML) directions were quantified while standing on fixed and sponge surfaces (dual task condition).

Table 2 - Represents the results of paired t-test statistics of RMS and Peak-to peak COP on AP AND ML directions on fixed and sponge surface that were performed to demonstrate the effects of the DT-TW intervention on core balance performance Square (RMS) COP excursion on fixed (F) and sponge (S) surface

Task	COP excursion	Fixed t-test, df (p value)		Sponge t-test, df (p value)	
		AP	ML	AP	ML
Eyes Open	RMS	NS	NS	NS	NS
	Peak to Peak	3.35,10 (0.001)	NS	NS	NS
Eyes Closed	RMS	NS	NS	-	-
	Peak to Peak	NS	NS	-	-
DT-Head Tracking	RMS	2.60,10 (0.005)	3.61,10 (0.001)	2.22,9 (0.010)	3.76,9 (0.0008)
	Peak to Peak	2.54,10 (0.005)	2.26,10 (0.009)	2.53,10 (0.005	NS
DT – Game 1	RMS	2.84,10 (0.003)	3.52,10 (0.001)	NS	2.60,9 (0.005)
	Peak to Peak	2.35,10 (0.008)	2.43,10 (0.007)	NS	NS
DT – Game 2	RMS	2.39,10 (0.007)	2.35,10 (0.008)	2.15,9 (0.010)	2.37,9 (0.008)
	Peak to Peak	3.18,10 (0.002)	2.36,10 (0.007)	3.45,10 (0.001)	NS

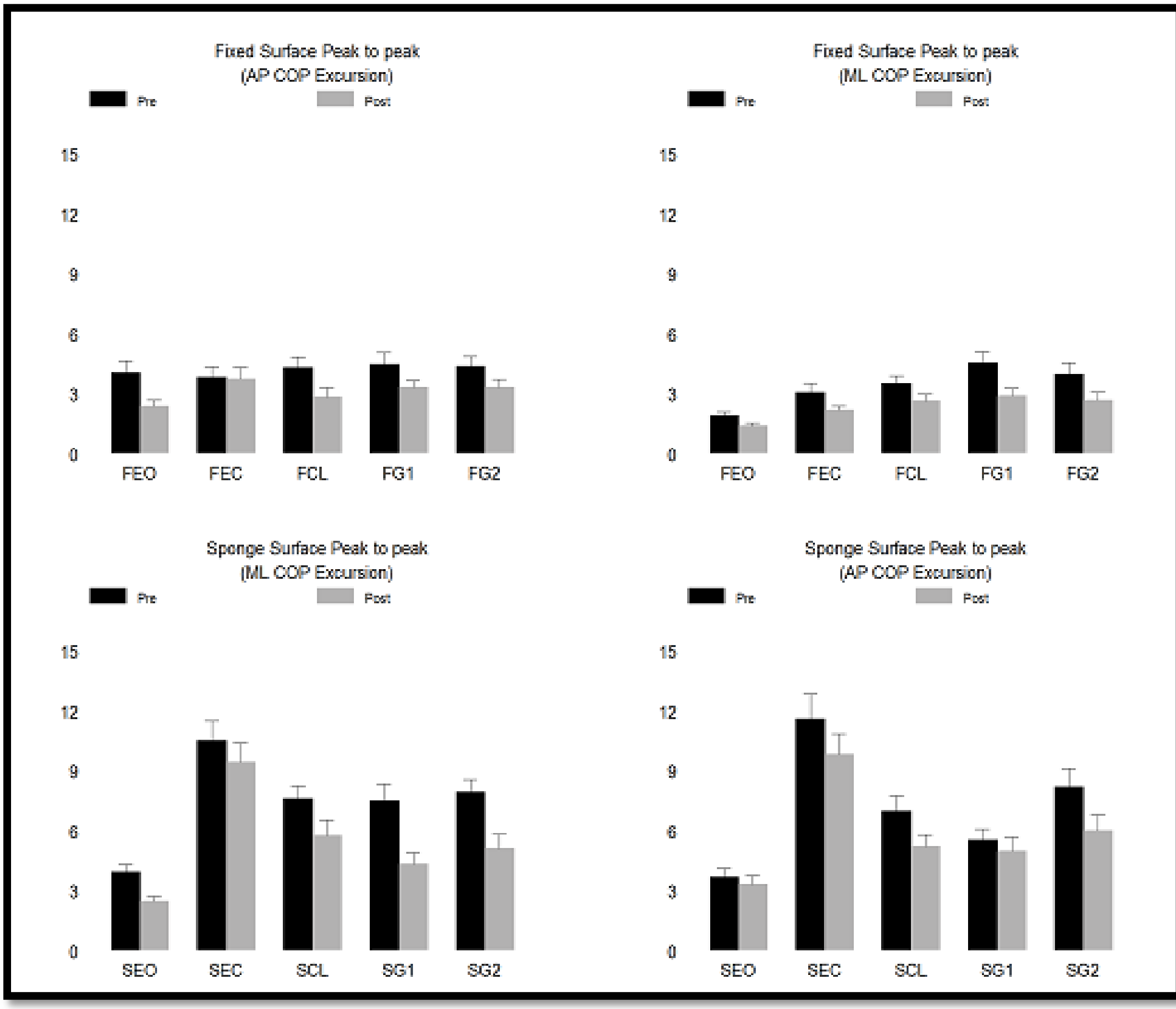
NS: Not Significant; RMS: root mean square; COP: centre of pressure; ML: Medio-lateral; AP: Anterio-posterior; df: degree of freedom; Significant: $p < 0.05$ (Bonferroni adjusted $P \leq 0.01$); DT: dual-task

Figure 6-Presents Group means and Standard Error of Mean (SEM) pre and post training of Root Mean Square (RMS) COP excursion on fixed (F) and sponge (S) surface



Anterio-Posterior (AP) and Medio-Lateral (ML) Centre Of Pressure (COP) excursions EO: Eyes open CL: close loop; G1: simple game; G2: moderate game; Pre - Pre intervention; Post - Post intervention

Figure 7- Presents Group means and Standard Error of Mean (SEM) pre and post training of Peak to peak COP excursion on fixed (F) and sponge (S) surface



Anterio-Posterior (AP) and Medio-Lateral (ML) Centre Of Pressure (COP) excursions EO: Eyes open CL: close loop; G1: simple game; G2: moderate game; Pre - Pre intervention; Post - Post intervention

The results of paired t-test revealed that there was a significant decrease in RMS COP excursion was noted in ML direction under all three tasks while standing on fixed and sponge surface. Significant improvement in peak to peak COP excursion was noted in ML direction under all three tasks while standing on fixed but not on sponge surface. No significant difference was noted during eyes open (EO) and eyes closed (EC) conditions while standing on fixed surface.

For AP-COP excursion, a significant decrease in RMS and peak to peak amplitude COP excursions were noted under all three dual task conditions on fixed and sponge surface except for peak to peak amplitude in game-1. No significant difference was noted during eyes open (EO) and eyes closed (EC) conditions while standing on fixed surface except for peak to peak on fixed surface.

Many participants fell in pre and post-tests while standing on sponge surface with EC. Hence, COP excursions for this condition were not analyzed.. However, the number of clients who fell on sponge with eyes closed decreased from six to two after completion of the DT-TW exercise program. Furthermore, three out of eleven participants progressed to the level of standing on a rubber disc and playing games.

Effect of DT-TW training program on Spatial and Temporal gait Variability

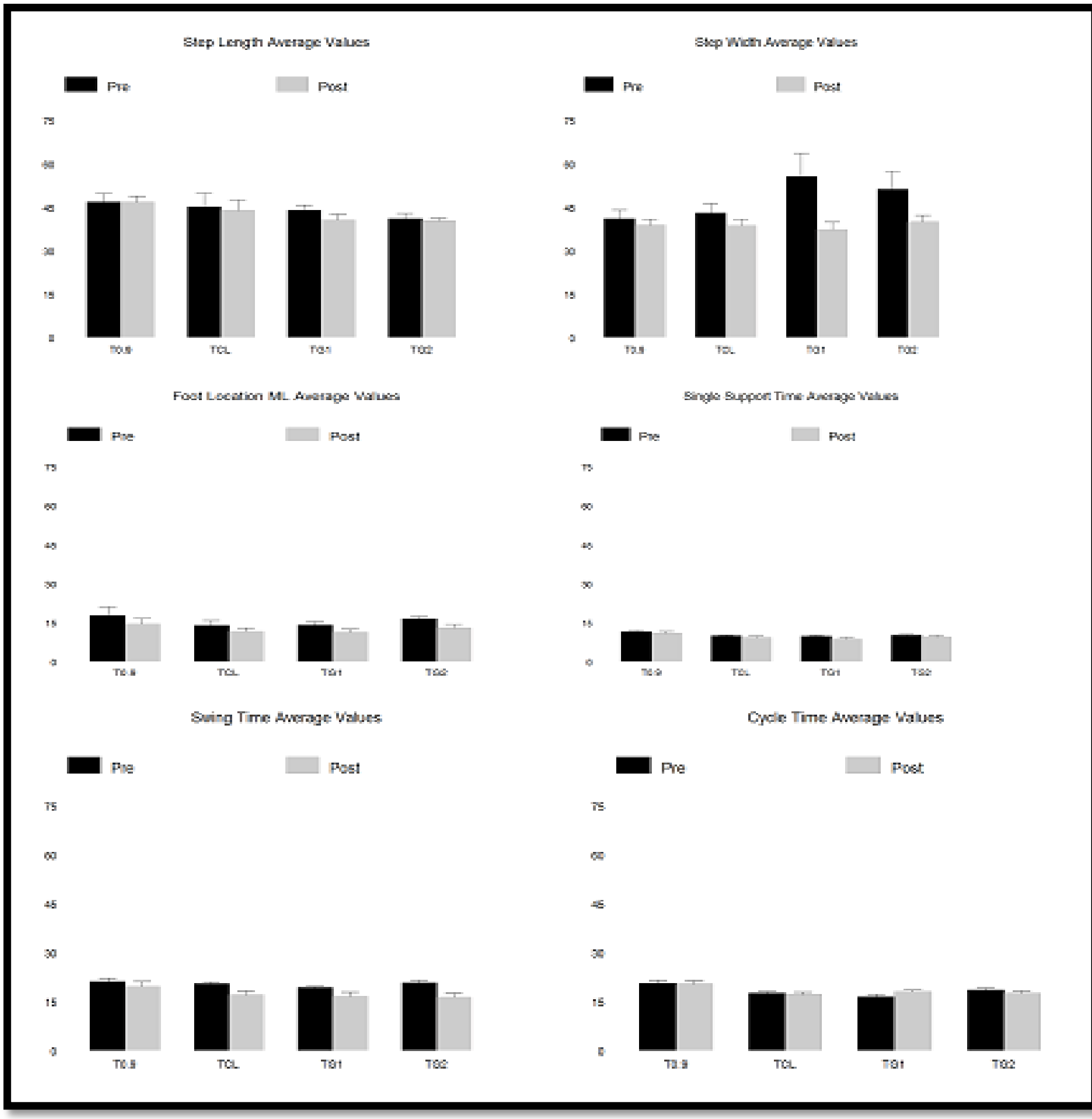
Spatio- temporal gait variables under dual task condition was quantified by average and COV (coefficient of variance) values.

Table 3 - Represents the results of paired t-test statistics of average and COV values while dual-tasking walking to demonstrate the effects of the DT-TW intervention on gait performance.

Task	Spatio-temporal parameters	Average t-test, df (p value)	COV t-test, df (p value)
DT-Head Tracking	Step Length	NS	NS
	Step Width	2.76,10 (0.006)	NS
	Single Support Time	NS	NS
	Swing Time	3.17,10 (0.003)	NS
	Cycle Time	NS	2.97,10 (0.004)
	Foot Location	NS	NS
DT-Game 1	Step Length	NS	2.82,10 (0.006)
	Step Width	2.34,10 (0.013)	2.14,10 (0.016)
	Single Support Time	2.36,10 (0.013)	2.16,10 (0.016)
	Swing Time	02.52,10 (0.01)	3.51,10 (0.002)
	Cycle Time	NS	2.50,10 (0.010)
	Foot Location	2.35,10 (0.013)	2.40,10 (0.012)
DT-Game 2	Step Length	NS	2.51,10 (0.010)
	Step Width	2.44,10 (0.011)	2.56,10 (0.006)
	Single Support Time	NS	2.41,10 (0.013)
	Swing Time	3.708,10 (0.001)	NS
	Cycle Time	NS	2.90,10 (0.005)
	Foot Location	3.09,10 (0.003)	2.66,10 (0.008)

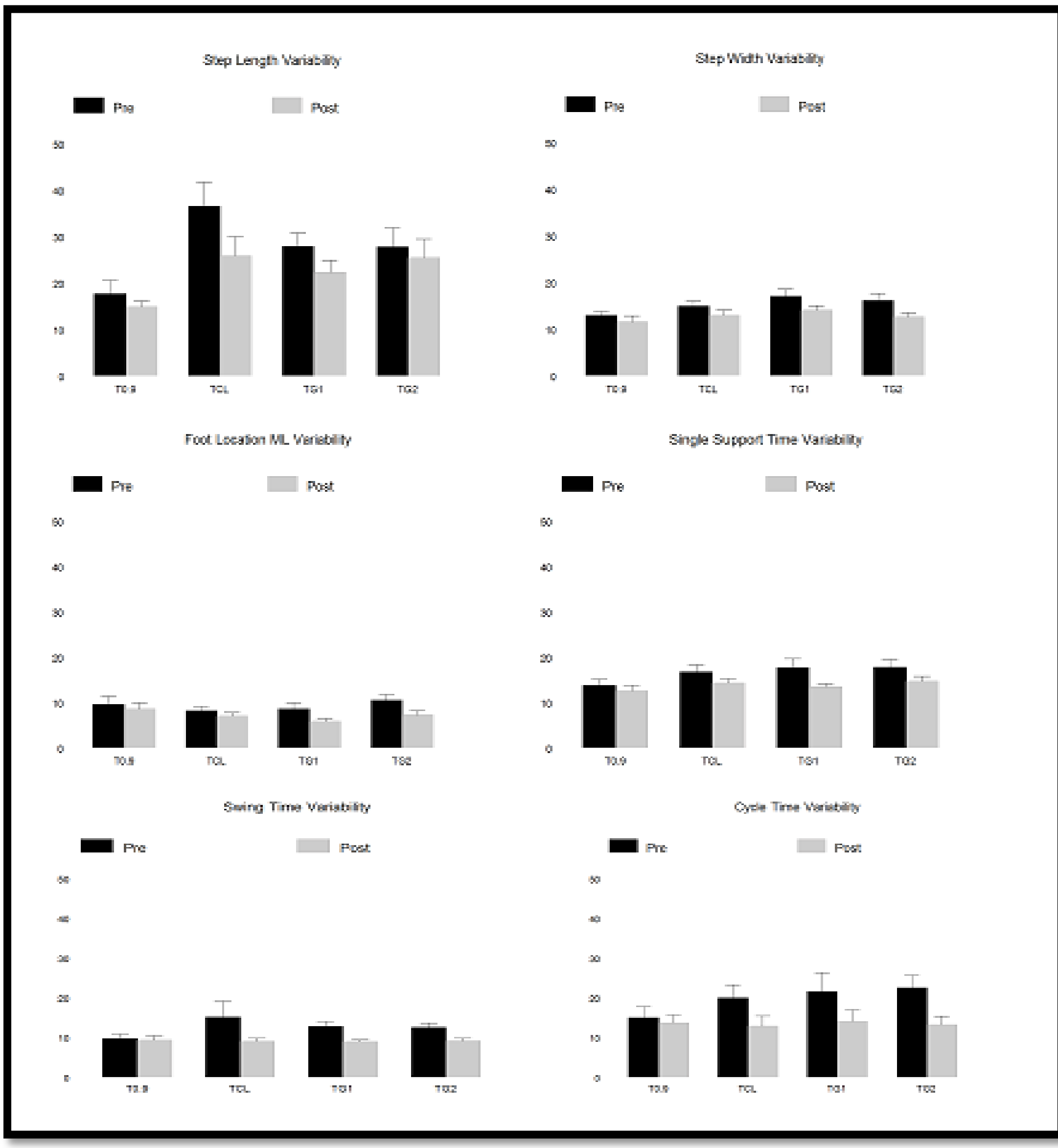
DT: dual-task; NS: not significant; COV: coefficient of variance; Significant: $p < 0.05$ (Bonferroni adjusted $P \leq 0.01$)

Figure 8- Presents Group means and Standard Error of Mean (SEM) pre and post training of averages values of spatio-temporal variable under dual task conditions



ML: Medio-Lateral; Pre - Pre intervention; Post - Post intervention; T: Treadmill walking; 0.9: normal walk; CL: close loop; G1: simple game; G2: moderate game

Figure 9- Presents Group means and Standard Error of Mean (SEM) pre and post training of Coefficient of Variances' (COV) values of spatio-temporal variable under dual task conditions.



Coefficient of Variances'; ML: Medio-Lateral; Pre - Pre intervention; Post - Post intervention; T: Treadmill walking; 0.9: normal walk; CL: close loop; G1: simple game; G2: moderate game

The results of paired t-test revealed that there was a statistically significant increase in the average values of step width under all three dual-task conditions, whereas foot location in ML direction increased in dual-task game1 and game-2. No significant improvement was seen in step length under the three tasks. COV values decreased for game-1 and game-2 for step length, step width and foot location in ML direction. No significant change in step length, step width and foot location in ML direction was noted for the head tracking task.

There was a significant increase in the average values of swing time under all three dual-task conditions, whereas single support time increased in dual-task game-1. No significant improvement was seen in cycle time under the three tasks. COV values decreased under all three dual-task conditions for cycle time, under game-1 and game-2 for single support time and under game-1 for swing time. Increase in average values and decrease in variability implies steady and rhythmic gait. One participants started training at lowest speed (0.5m/s, average was 1.0m/s) and needed handrails for balance. By the end of the DT-TW training program, this participants could walk on the treadmill without handrails and tolerate speeds up to 1.5m/s.

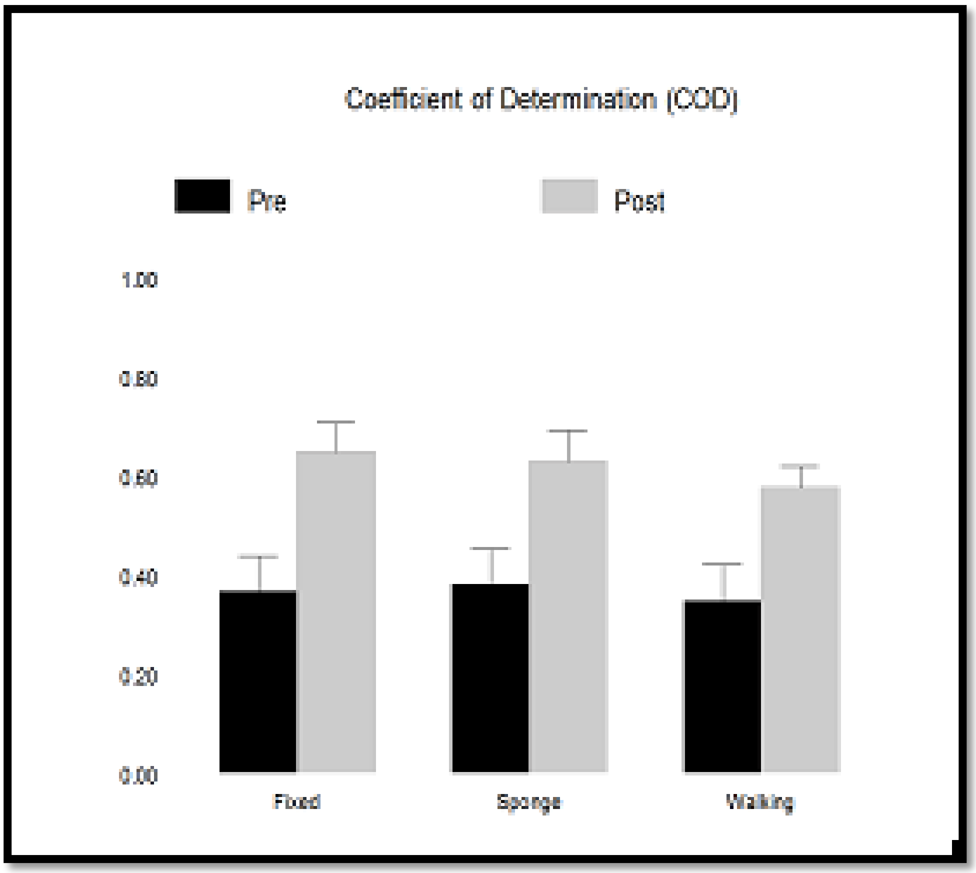
Effect of dual-task treadmill walking training program (DT-TW) on Head tracking (gaze stability) performance

Head tracking performance under dual task condition was quantified by measuring COD values.

Table 4 represents the results of paired t-test statistics of COD values while standing on fixed surface, sponge surface and walking to demonstrate the effects of the DT-TW intervention on head tracking performance.

Conditions	**COD t-test, df (p value)**
Fixed surface	-4.13,10 (0.002)
Sponge surface	-2.66,10 (0.020)
Walking	-2.66,10 (0.020)

Figure 10- Presents Group means and Standard Error of Mean (SEM) of pre and post training of COD values under dual task conditions



COD: Coefficient of Determination (COD) Pre - Pre intervention; Post - Post intervention

The results of paired t-test revealed an improvement in the head tracking performance from pre to post training under all three conditions

Effect of DT-TW training program on cognitive game task performances

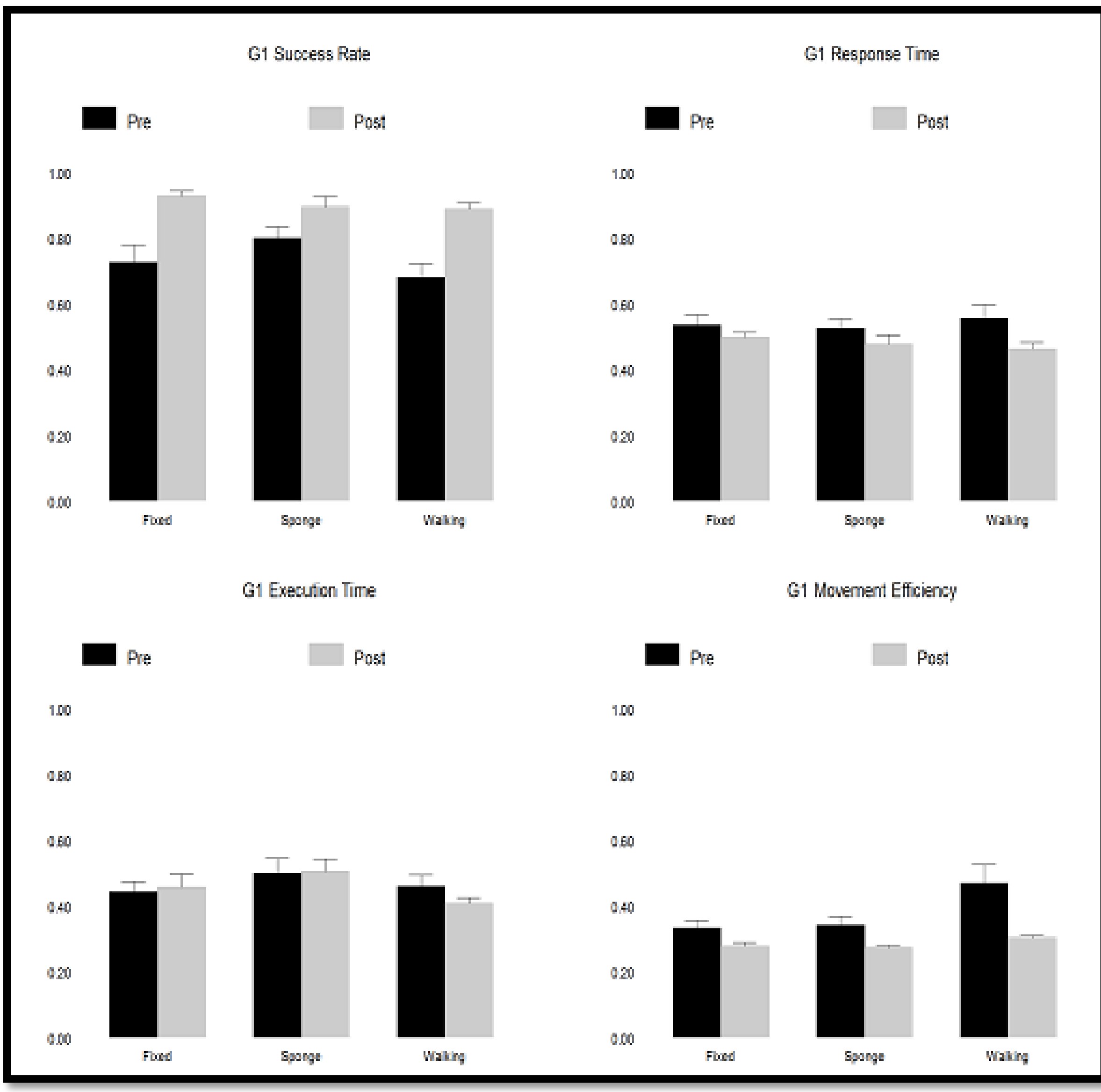
Cognitive game performance was under dual task condition was quantified by success rate, response time, execution time, movement efficiency.

Table 5 represents the results of paired t-test statistics of these values while standing on fixed surface, sponge surface and walking and playing simple game (G1) and moderate game (G 2) to demonstrate the effects of the DT-TW intervention on head tracking performance.

Condition	**Parameters**	**G1 t-test, df (p value)**	**G2 t-test, df (p value)**
Fixed	Success Rate	4.02,10 (0.000)	4.05,10 (0.000)
	Response Time	NS	2.36,10 (0.013)
	Execution Time	NS	NS
	Movement Efficiency	2.66,10 (0.008)	NS
Sponge	Success Rate	2.30,10 (0.013)	3.15,10 (0.003)
	Response Time	NS	NS
	Execution Time	NS	NS
	Movement Efficiency	2.70,10 (0.007)	NS
DT-Treadmill Walking	Success Rate	-5.31,10 (0.000)	-5.717,10 (0.000)
	Response Time	NS	3.07,10 (0.004)
	Execution Time	NS	NS
	Movement Efficiency	3.00,10 (0.004)	NS

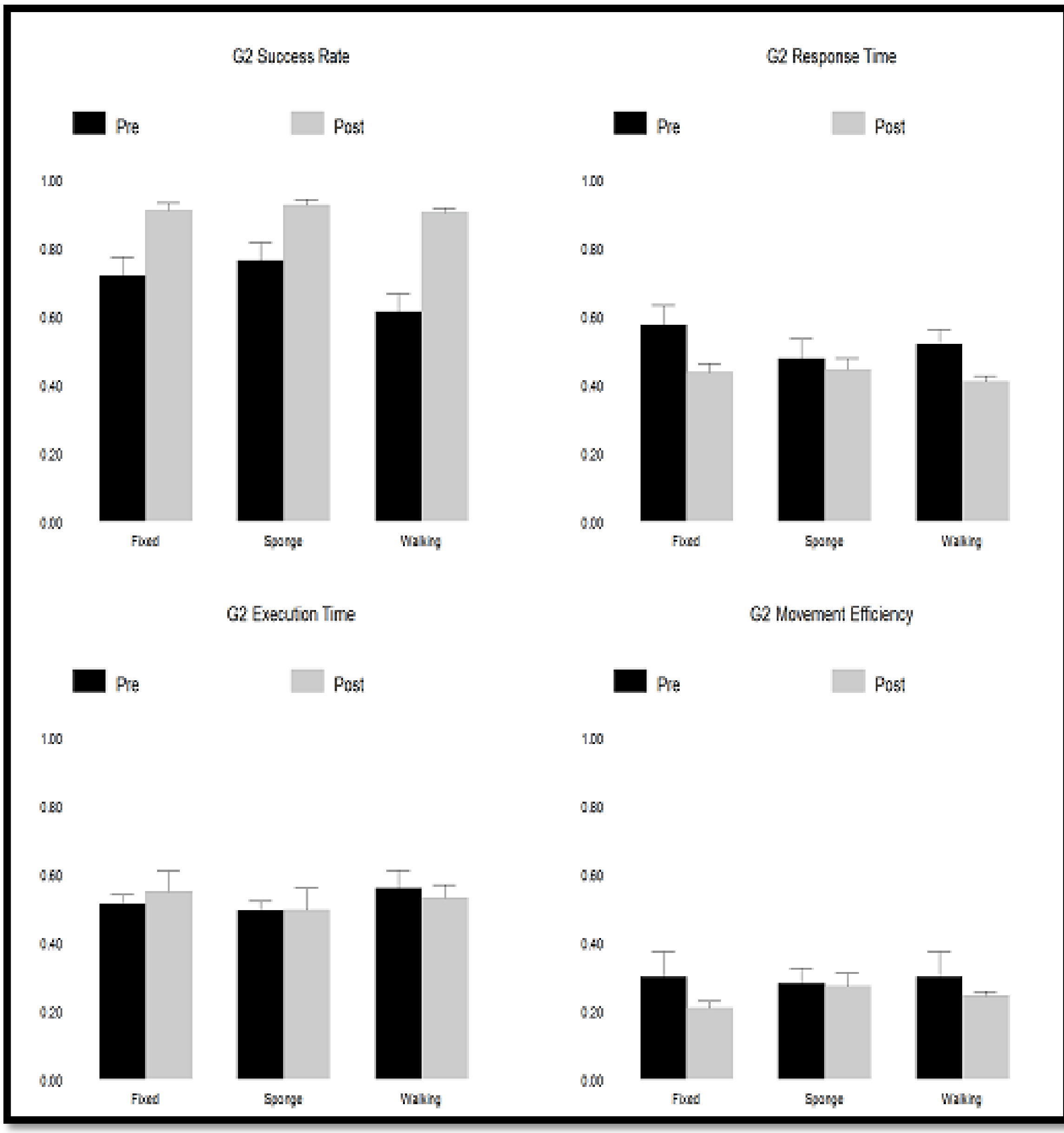
DT: dual-task; NS: Not significant; G1: Simple game; G2: Moderate game; Significant: $p < 0.05$ (Bonferroni adjusted $P \leq 0.01$)

Figure 11 - Presents Group means and Standard Error Mean (SEM) of pre and post training of the percentage of success rate, response time, execution time, residual error and the movement efficiency values while performing cognitive Game 1 (G1) under different tasks.



G1: Simple game; Pre- pre intervention; post: post intervention

Figure 12 - Presents Group means and Standard Error Mean (SEM) of the percentage of success rate, response time, execution time, residual error and the movement efficiency values while performing cognitive Game 2 (G 2) under different tasks.



G2: Moderate game; Pre- pre intervention; post: post intervention

The results of paired t-test revealed a significant increase in success rate and movement efficiency from pre to post intervention for all test conditions. However a significant improvement was noted in response time under fixed and dual-task walking condition while playing game-2. No significant improvements were noted in execution time while playing the games (game-1 and game-2) under all three dual task conditions.

Effect of DT-TW training program on Neuropsychological performance

Neuropsychological performance was quantified by visual search, verbal fluency and trail making test (parts A and B).

Table 6 represents the results of paired t-test statistics of these values to demonstrate the effects of the DT-TW intervention on head tracking performance

Conditions	**Means± SEM (pre)**	**Means± SEM (post)**	**t-statistics, df (p value)**
Visual search			
-Right (30)	21.09±1.79	21±1.35	NS
-Left (30)	21.27±1.99	21±1.34	NS
-total (60)	42.36±3.74	42±2.63	NS
Verbal fluency	12.81±1.17	14.09±1.41	NS
- F (25)	11±1.19	13.09±1.26	NS
- A (25)	14.90±1.33	14.72±1.23	-3.42,10 (0.002)
- S (25)	16.36±1.39	17.72±1.43	NS
- Animal (25)			
TMT-part A	38.18±3.03	36±3.02	NS
TMT-part B	118.27±16.78	78.18±7.40	2.76, 10 (0.006)

TMT: trail making test; SEM: standard error mean; df: degree of freedom; Significant: $p< 0.05$ (Bonferroni adjusted $P\leq0.01$); NS: Not Significant

As presented in the table, results revealed that a significant improvement was noted only under trail making test part B (took less time) and verbal fluency (A) (participants recited more word post training).

Effect of DT-TW training program on physical performance:

Physical performance was quantified by 5 times sit to stand test (5x STST), speed over 25m walk and distance covered while performing 6 minute walk test (6MWT).

Table 7 represents the results of paired t-test statistics of these values to demonstrate the effects of the DT-TW intervention on head tracking performance

Conditions	**Means± SEM (pre)**	**Means± SEM (post)**	**t-statistics, df (p-value)**
6MWT speed (over a distance of 25 m)	1.69 ± 0.15	2.02 ±0.11	-2.261, 10(0.047)
6MWT distance (215.16 m/lap)	551.49 ±43.44	616.99 ±54.44	-3.331, 10 (0.008)
5xSTST	10.90 ±0.93	9.45 ±0.60	-2.261, 10 (0.0047

6MWT: six minute walking test; 5xSTST: five times sit to stand test; df: degree of freedom; Significant: $p< 0.05$

As presented in the table, results revealed that there is a statistically significant difference in 6MWT speed, 6MWT distance and 5XSTST from pre to post tests. The Minimal Detectable Change (MDC) values were of 65.5 m for 6MWT distance, 0.33 m/s for speed over 25m.

Results of the qualitative study (Feasibility of the DT-TW training program and lived experience):

Sixteen training and 4 assessment sessions were completed by all the eleven participants. Seven participants were called for interviewed individually post training to get their feedback on the training program as four did not respond to the calls made. The Specific questions about the program such as: 1) Was the exercise program was appropriate, flexible, and achievable?; 2) Were the cognitive games engaging and motivating?; 3) perceived exercise benefits; 4) perceived difficulties with the exercises and using the technologies; 5) Recommendation and comments for improving the exercise program were asked. Following is the textural description and explanation of the participants responses:

1) Was the exercise program was appropriate, flexible, and achievable?

All participants reported that the exercises were adequate, well designed and practically doable without any difficulty. As none of the participants ever played computer games, they were fascinated to see the different aspects of the game. They found some games interesting and some not. They thought the program pace and intensity set for the program was adequate. The participants also found the program to be challenging, fun and interactive. The participants reported, " I think that the exercise program was doable"; "It was well designed and the duration was appropriate" ; " I have never done this type of exercise. It was challenging and involved lot of concentration and balance"; " The duration seemed enough. Helped me improve my balance and walk better".

2) Were the cognitive games engaging and motivating?

The seven participants that were interviewed reported that playing computer games helped them concentrate better, focus and respond faster. It made them more oriented and alert. It improved their multitasking ability. Some of the games were liked and some were not. They found the games engaging and liked the fact of how they made them conscious and concentrate. One participant did not enjoy the program. He participated in it as he wanted to try it and see what it offered. He thought the games were engaging but wanted more strength training exercises. The participants reported, " I was difficult to play initially as have never played games before"; "The games kept me engaged"; "Every game was different and had different challenges that need to be faced"; "Did not like the games. Did it as was enrolled in the program"; "Different levels of the games had different challenged that made the game interesting".

3) Perceived exercise benefits

Most of the participants described the exercise program was beneficial. All seven participants that were interviewed found it challenging. One participant reported that the program helped him get up from the chair and cross over a hurdle in his basement. All the participants were amazed to find out how they could manage to perform both things simultaneously and coordinate well as none of them played video games before. The participants reported, " Made a difference in the day to day activity"; "Made me more aware of my surroundings"; Helped me balance better"; "Improved multitasking"; "Participated to know if the game could improve my balance"; "Participated because my friend suggested".

4) perceived difficulties with the exercises and using the technologies

All the participants found the head mouse a little difficult to use. At time the mouse would drift away to one side of the screen as a result of sudden movements of the head. This was annoying to them as it would result in turning the head to extreme sides thus making it difficult to play. There was no problem with the mouse while playing the games in standing. Out of the 12 games that were played throughout the training program, the mouse worked perfectly fine on 6 of the games where the movements were only in one direction. The participants reported, " Understanding the game was difficult initially"; "The levels had different challenges which were not clear at the beginning "; "The head mouse gave trouble"; "Everything was fine and doable"; "The program was easy"; "I don’t think I had any problems with the program, I think it was easy to handle".

5) Recommendation and comments for improving the exercise program were asked

All participants’ interviewed found the duration and intensity adequate. They reported that the program was well conducted and delivered. The instructions were clear and the necessary help in understanding the program was provided by the therapist. The program was extremely worthwhile and satisfactory. The participants reported, " I would keep doing it if provided with the proper setting"; "The mouse should be easy to handle."; "An easy version would be good"; "It was different from regular activities".

Discussion:

This study evaluated the effects of a dual-task program on balance, gait, gaze and cognition on 11 healthy community dwelling older adults. The participants played different types of computer games which trained different domains of executive function while standing on a sponge and while walking on the treadmill. Results revealed statistically significant improvements in core balance, gait, gaze and cognitive function.

DT-TW and core balance:

Core balance was assessed by measuring the COP excursion while standing on a fixed and sponge surface. A couple of studies have reported an increase in body sway with eyes close while standing on a sponge surface (Desai et al., 2010; Shumway-Cook & Horak, 1986). The finding of the study reported a reduction in the COP excursion while standing on the fixed and sponger surface.

During the training sessions, the participants had to play different games for 8 weeks while standing on a compliant surface. Standing on a compliant surface and playing games is more challenging as the ground reaction forces are difficult to interpret. Thus, the participants have to rely on visual and vestibular feedback to gain spatial awareness and improve their performance. The results show a lower COP excursions (participants swayed less) post DT-TW training indicating increased postural stability. While standing on the compliant surface and playing games, the participants had to rotate their heads. As participants could not predict the ground reaction forces, there was an increase in physical and cognitive demand to maintain balance. One reason for the reduced COP excursion could be that the participants had to stabilize their head and trunk, while standing and tracking objects as studies have shown that head rotation while standing on a sponge surface increases body sway and spatio-temporal variability (Desai et al., 2010; Duysens et al., 2008; Pang, Lam, Wong, Au, & Chow, 2011). Another reason for the improvement in core balance can be that standing on the sponge surface and performing slow head rotations requires smooth pursuit. As the head and eyes moved in the same direction while playing the games, the Visuo Ocular Reflex (VOR) compensation was needed to be cancelled to foveate. This assisted in stabilizing the head, thus reducing body sway (Tony Szturm et al., 2015). Szturm et al. (2011) performed a study which studied the effect of interactive computer games on balance in community dwelling older adults. Szturm et al. (2011) observed significant improvement in balance among older adults who played the interactive games while standing on the sponge. Compared to our study, Szturm et al. (2011) did not train or test executive functions in older adults and the dual-task load was not as heavy, but they did have dual-task training on a compliant surface. Hence we conclude that training on a compliant surface may have increased vestibular feedback and spatial orientation, leading to a decrease in body sway and increased stability.

Out of the five tasks, eyes closed while standing on the sponge was not analyzed due to loss of balance among most participants at initial assessment. Though the level of significance was not analyzed, only 3 out of 11 participants lost balance post training during this task as compared to 7 out of 11 participants losing balance during pre-training assessments.

Furthermore, as mentioned in the results, three out of eleven participants progressed to the level of standing on a rubber disc and playing games. This outcome is in accord with the work conducted by Hirase et al. (2015), where the participants stood on a rubber foam pad and performed balance training exercises for an hour, once a week, for six months. Hirase (2015) showed that there was an improvement in dynamic balance, measured by Time Up And Go Test, and reduced fear of falling which, was measured by Fall Efficacy Scale. Results from Hirase (2015) suggest that an exercise program on a compliant surface improves balance. This study was different from our study because there was no dual-task component.

DT-TW and spatio-temporal gait parameters:

Our study used different types of cognitive games while walking to study the effect on spatio-temporal gait parameter. The results showed that older adults experienced a decrease in spatio-temporal variability. Lower variability is indicative of greater postural stability during walking (Qu, 2014).

Treadmill training is easier to use as we do not require long corridors and also offers improvements in balance and gait parameters (Bello et al., 2013; Elazzazi, Chapman, Murphy, & White, 2012). Hollman et al. (2010) looked at calculating the number of strides required to measure mean velocity, cadence, and stride velocity variability. Their results showed that to assess velocity and cadence, 4 and 9 strides during normal walking respectively, and 9 and 20 strides during dual-tasking respectively, are sufficient to achieve a desired reliability. To assess stride variability, 60 strides during single task and approximately 370 strides during dual-task are needed. Hence, our study used treadmill walking as it provided the 40-50 steps, while being comfortable for training and assessing spatiotemporal gait parameters. In addition, the treadmill offered a constant gait speed, such that the effect of dual-tasking on gait and cognition could be measured accurately. Dorfman et al. (2014) studied the effect of dual-task training on balance, gait, and cognition in older adults. Dorfmans' (2014) dual-task training program consisted of 18 sessions in which the participants walked on the treadmill while answering questions from a short story they listened to, performing simple additions, subtractions, multiplications, and divisions, or generating semantic and phonetic lists of words. Dorfman (2014) proved that there was an improvement in balance (Berg Balance Test), and dual-task gait parameters like speed, step length with reduction in stride time variability (serial 3 subtraction while walking), and Trail Making Test (TMT) part B. Dorfman (2014) study did not train executive function as the training task consisted of recall memory and working memory. There is also no evidence of dual-task training on cognition as there is no account of their performance on serial 3 subtractions (Dorfman et al., 2014). A similar finding was reported by Mirelman et al., 2011 showing improvements in gait speed, and reduction in gait variability in older adults with Parkinson's disease, by combining treadmill walking and virtual reality environments. Our findings of improved gait parameters and decreased variability are consistent with the results of these studies.

Allocenteric reference frame is a frame that provides information of one object with respect to the other and egocentric reference frame provides information of the object with respect to the body (Lithfous, Dufour, Blanc, & Després, 2014). These frames are significant components of executive function which help in keeping equilibrium and preventing falls (Murray et al., 2010; Nagamatsu et al., 2009). The games played during DT-TW program provide optokinetic stimulation and VOR compensation. The treadmill offered constant speed which is integral to reducing gait variability because it allowed our participants to know their position in space (Muir, Speechley, et al., 2012). This helped in stabilizing their trunk, allowing smooth head rotations and reduced passive head motion. Walking on the treadmill caused the participants to walk continuously and not to stop to avoid losing balance. This encouraged a rhythmic gait pattern and improved spatial awareness. This was specially seen in one participants who could only tolerate the lowest treadmill walking speed (0.5m/s, average was 1.0m/s) and needed handrails for balance at the beginning of the DT-TW program . By the end of the program this participant could tolerate a speed of 1.5m/s. As the training program progressed, the participants learnt new methods to adapt to the heavy demands of divided attention. All the participants began to stumble less, gained confidence, and acquired a rhythmic pace making their foot location coherent.

Thus, the DT-TW training program may have likely resulted in improvements of the allocentric and egocentric spatial processing of the participants. For example, the participants spatio-temporal gait parameters under dual-task testing improved post intervention. It prepared them to become more mindful of their surroundings. This led to a decline in gait variability. The DT-TW program thus proved to be a motor-cognitive training approach that provides a platform where participants' balance strategies can be retrained to overcome gait inadequacies.

DT-TW and Head tracking, cognitive games performance:

While standing, the head should be stable so that the eyes can foveate on moving targets. This is where smooth pursuit and optokinetic functions become invaluable. They assist in visual compensation to maintain the image stable on the retina during slow head rotations (Baloh, R & Kerber, K, 2011). The participants were asked to play a variety of games while standing and walking. The computer games were purchased from Big Fish games (http://www.bigfishgames.com) which consisted of the following:

- Action ball
- Brave piglet
- Aquaball
- Jet Jumper
- Birds Town
- Butterfly escape
- Abundante
- Bejewelled
- Feeding Frenzy

These games had unpredictable and predictable movements which required rapid head movements and visual searching. Studies have shown gaze stability training programs should have unpredictable and predictable head movements (Barnes & Crombie, 1985; Schubert, Migliaccio, Clendaniel, Allak, & Carey, 2008). The movements of the game sprite in the DT-TW program were synchronized with the participants'. In order to play well, the participants had to be quick and their head-movements had to be precise. Also along with these precise head movements, body stability was necessary to maintain balance. which is evident from the findings of this study showing a decrease in COP excursion while standing on a sponge surface.

Che, Hsieh, Wei, & Kao, (2012) conducted a computer-aided vestibular rehabilitation training program for four vestibular hypofunctional participants (one middle aged and 3 older adults) using the Nintendo Wii. The participants had to play one head tracking, and two interactive games while sitting. This was coupled with a home exercise program done while sitting, standing on a sponge surface, and a fixed surface. After 6 weeks of training, significant improvements in balance Time up and go test (TUGT) and Dynamic Visual Acuity (DVA) using sensory organization testing were observed in the four participants. Because in the Che (2012) study interactive games were played while sitting, we do not know if the games had an impact on balance or if it improved dual-task ability. Our study is consistent with the Che (2012) study in terms of DVA. We can conclude that, the improvement in the head tracking performance may have been due to a decrease in COP excursion which resulted in a lesser body sway and in increase in the smooth pursuit ability of the participants.

While walking, there is a great deal of passive head movement (Lafond, Corriveau, Hébert, & Prince, 2004). Hence the VOR has to compensate to reduce the slipping of the image from the retina to reduce blurred vision (Hillman, Bloomberg, McDonald, & Cohen, 1999; Scherer, Migliaccio, & Schubert, 2008). In the DT-TW program, the games caused random head movements, along with an increase in passive head movement because of walking. In order to play the games well, participants had to foveate and fixate to avoid blurring of vision. Thus the DT-TW program caused participants to efficiently divide their attention to maintain steady gait and to not fall off of the treadmill. It has been observed that tracking an object while walking reduces trunk motion (Tony Szturm et al., 2013). A reduction in the trunk motion reduces passive head movement, allowing the eyes to foveate on objects. The results in our study show a decline in gait variability, making the gait more rhythmic and steady. This steady rhythmic gait in turn may have reduced passive head motion. Reduced gait variability thus provides a possible explanation to our other observation of improved head tracking performance. Tony Szturm et al., (2015) conducted a 12 week home exercise program where the participant played interactive computer games while standing on the sponge. Gaze performance was analyzed by tracking an object in horizontal axis while standing on a fixed surface, sponge surface, and walking on a treadmill. The results indicated a significant improvement in head tracking performance while standing on the sponge surface and during treadmill walking. Our study is in accord with the results from Szturm (2015). We can conclude that, the improvement in the head tracking performance while walking may have been due to a decrease in spatio-temporal gait variability which and VOR compensation.

Computer games when combined with physical activities have therapeutic effects (Bateni, 2012; González-Fernández et al., 2010). Anderson-Hanley et al. (2012) combined virtual reality environment with cycling to study the effect on executive function in older adults. The outcomes indicated an improvement in executive function along with preventing and suppressing mild cognitive impairment(Anderson-Hanley et al., 2012). The finding in our study demonstrate that success rate and movement efficiency increased in game-1, and success rate, response time, and movement efficiency increased in game-2. Game-1 and game-2 are assessment games. These games required participants to pay attention, process and respond to targets, and avoid distracters while standing, and walking. The BigFish games show many similarities with the assessment games but had different characteristics - wherein the participants had to move the game sprite left, right, up and down; catch the target and avoid distracters; move the target to get the desired outcome to win etc. The BigFish games targeted different domains of executive function like mental flexibility, processing time, reaction time, set shifting, etc.(Edwards et al., 2009; Kueider et al., 2012; Mirelman et al., 2011). None of the participants in the training program had played computer games before. We can conclude that, the improvement in the cognitive game performance may have been due to the games played in the DT-TW program. Thus, an increase in assessment game scores from the playing of BigFish games during DT-TW program showed that executive function can be developed with a task oriented approach.

We have found that many papers which claim to train or test executive function during dual-task activity, do not accurately target executive function. Instead, the concurrent cognitive tasks they choose are usually reciting words or letters, counting backwards, or calculating numbers from a pre-determined number (Al-Yahya et al., 2011; Dorfman et al., 2014; Montero-Odasso, Muir, & Speechley, 2012).These tasks test working or recall memory, but not executive function. In contrast the concurrent cognitive task selected in our study did train and assess executive function. The games we selected developed different aspects of executive function such as processing speed, reaction time, visual search, mental flexibility, task shifting, etc which we intended to train.

Neuropsychological test:

The TMT used to evaluate executive function measures mental flexibility, task-switching, and visual spatial skills (Herman et al., 2010; McGough et al., 2011; Montero-Odasso et al., 2009). It is associated with reduction in gait speed, gait variability, and poor cognitive performance in older adults while dual-tasking (Coppin et al., 2006; Montero-Odasso et al., 2009; Siu, Chou, Mayr, Donkelaar, & Woollacott, 2008; Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009; Yogev-Seligmann et al., 2010). This study showed an improvement in TMT-B which might be an effect of the DT-TW training program. As mentioned earlier, it is seen that the games involved mental flexibility and visual search tasks as the participants had to catch targets and avoid distracters (Anderson-Hanley et al., 2012; Coppin et al., 2006; Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Persad, Jones, Ashton-Miller, Alexander, & Giordani, 2008; Yogev-Seligmann, Hausdorff, & Giladi, 2008).

Some of the participants could not finish the TMT-B test before training. But all of them did complete the test post training. This implies that the DT-TW training program may be responsible for the improvements in their mental flexibility and visual search functions. There were no substantial changes in TMT-A but the time needed to finish the test decreased post training. This suggests that a modest growth in executive function above the age of 70 may be beneficial to maintain steady gait (Tombaugh, 2004). Similarly, though a significant improvement was not seen in verbal fluency test, the participants did enumerate more words under each category post the intervention. Thought the games did not train aspects of verbal fluency (recall memory), the improvements demonstrate that there may have been a transfer of the effects of DT-TW program in recall memory function. This is accord with a study conducted Oppezzo

& Schwartz et al. (2014)which showed that treadmill walking can improve creative and cognitive abilities.

Physical Performance:

Sedentary lifestyle in aging is associated with a decrease in balance, endurance, and mobility leading to increased fall risk and injuries (Hirvensalo et al., 2000).Our study reported a significant improvement in 6 MWT, gait speed, and 5 STST which was a result of treadmill training (Pelosin et al., 2009; Zhang et al., 2013). A minimal detectable change (MDC) is a statistical tool which helps in determining the clinical significance of the smalls amount of changes derived from a test battery (Ries, Echternach, Nof, & Gagnon Blodgett, 2009). In the current study an MDC value were 65.5 m in 6 MWT distance and 0.33m/s for speed over 25 m. This finding is in accord with the study conducted by Mangione et al (2010) who studied an MDC value of 6MWT distance in fifty-two elderly African Americans participants (mean age78 years) The participants were asked to cover as much distance as possible in 6 minutes over a 100ft long path. The participants were tested twice over a one week period. The results of MDC in Mangione et al (2010) study were 65.5 m in 6 MWT distance and 0.19 m/s for speed over 2.4m. Thus, we can conclude that one of the reasons for the improvement in core balance and spatio- temporal gait was due to an improvement in the physical performances of the participants.

Feasibility:

The DT-TW program reported 100% compliance and adherence. Adherence and motivation are very vital to an exercise regimen as only then do we get beneficial results. For this to happen, proper guidance, instructions, and help were provided to the participants to ensure that they understood the games and played well. Not understanding the game or the equipment while playing would have slowed down the participants' progress, resulting in frustration that impacts the outcome (Agmon, Perry, Phelan, Demiris, & Nguyen, 2011; Jung, Li, Gladys, & Lee, 2009).

Three participants dropped out after the initial assessment. The reason for dropping out were injuries to the shoulder while performing regular physical exercises, unexpected illness, and going on a vacation. No adverse effects such as falls or injury were noted during the training program.

Lived Experience:

Additional insight into the program is gained by understanding the ‘lived experiences’ of the participants after they completed the program. The sub-questions that emerged were based on the participants’ experiences during the program. The findings represent interpretations of the interview and the direct quotes from participants. The general finding from the interview was that participants found the DT-TW program to be well designed. The challenges and interactions faced during the DT-TW program made participants more comfortable with their daily life activities. The physical and cognitive load provided by the DT-TW program made the participants aware of their condition; resulting in learning new skills and strategies to overcome their challenge better.

Seven of the eleven participants found the DT-TW program achievable. One participant claimed that, "the exercise program was doable, the intensity and duration was appropriate". While another participant reported, "the DT-TW program was fun, interactive and challenging". These remarks illustrate that the DT-TW program was well designed in providing dual -task balance and gait training. Participants further reported that the instructions were clearly provided, and the protocol was well described. This helped participants understand the program better, making them more comfortable, and engage more fully with the program.

The participants faced a lot of challenges since they had never played computer games or participated in any DT-TW program. Most of the participants' reploed on the lines of, "it was difficult to play the games as I have never played computer games before". Despite the novelty, most participants found the games to be both interesting and engaging. One participant reported, "every game was different and had different challenges that need to be face" while another participant quote, " different levels of the games has different challenges that made it interesting and engaging". Most participants took several sessions to grasp the nuances of the games, while simultaneously balance or walk on the treadmill. Once the participants were familiar with the games, they found training experience to be fun and enjoyable. Many were surprised and amused with their performance throughout the training program. Most participants marveled at how different the training was and how they had never participated in anything similar before. For example one participant reported, "I have never done this type of exercise. It was challenging and involved lot of concentration and balance".

The participants found the program to be of benefit in their day to day activities. It made them aware of their surroundings. They could dual-task, or complete their task without having to stop for other activities. For instance, one participant reported, "while shopping in an aisle, I can look around for the stuff and walk simultaneously which was difficult to do earlier", while another participant reported, "in my basement I have a little obstacle that needs to be crossed in order to take the stairs. Earlier I had to hold the wall to cross the obstacle but now, I can cross it without any support". Participants reported that the training helped improve their balance and multi-tasking ability.

The participants did have some difficulties during the sessions. Most participants found it difficult to use the head motion mouse because it shifted during the game. This shifting caused the cursor or game sprite to deviate to the side of the screen. This movement of the mouse was due to sudden or jerky movements by participants and could be avoided with more smooth head rotations. This incidence suggests that there is a need for a better technology to stabilize the mouse and the cursor. In addition, some participants did not like certain games and let the examiner know. Furthermore, one participant reported that he could not understand how the games would benefit his dual task ability. Despite these concerns, most of the participants provided us with the feedback that they would like to continue with the program if they are provided in a proper and easy to use setting. Their strongest recommendation was about improving the head motion mouse to make the games easier to play.

To summarize, we can say that findings from the ‘lived experiences’ of the participants support the quantitative findings of the DT-TW program.

Conclusion:

Dual-tasking is vital to Activities of Daily Living. Dual-task impairments overwhelmingly affect older adults, and contribute profoundly to age-associated morbidity (Hirvensalo et al., 2000; Mirelman et al., 2012; Muir, Gopaul, et al., 2012; van Iersel et al., 2008). Our pilot DT-TW training program offers one approach to tackle this growing concern.

The study showed that it is possible to retrain dual-task functions among older adults by combining physical exercise with computer games. It illustrated a model of how an exercise program can be fun, interactive, and provide assistance, and may prevent or reduce risk of injuries. Our study supports the idea than even in advanced age, new skills and techniques can be learnt. Older adults can adapt to changes and be confident of their surroundings. They do not need to be proficient in learning to benefit from new methods used in the training program. DT-TW training may also prove to be an alternative to physiotherapy treatment, which can be prohibitively expensive for some.

Feedback from participants provided valuable insight about experiences of older adults with using modern technologies to overcome their physical and cognitive challenges. Whether there is significant morbidity and mortality benefits to DT-TW training was beyond the scope of this pilot. A larger study with appropriate controls will lend further credibility to the DT-TW program.

To conclude, our study supports that DT-TW training program is feasible, is applicable to people with varying levels of base-line health, and easy to administer. It provides a roadmap of how to combine technology and computer games to improve the health of older people. We hope to further explore this emerging area of research.

Clinical Significance:

The findings from the DT-TW program provided information on training balance, gait, gaze and cognition in older adults through dual-task training program. We believe that this will reduce injuries in older adults, especially from falls. This will result in lower morbidity and mortality, reduce caregiver burden, and reduced healthcare spending over time.

Limitations:

- One limitation of this study is that it does not have a matched control group to understand the complete effect of the DT-TW program.
- Second limitation of the study is that it has a small sample size making it difficult to generalize the data.
- Third limitation of the study is we do not know if the effect of DT-TW program translated over day o day activities as the participants were not tested for tests like Berg balance test, Time-up and go test etc..
- Lastly, a randomized controlled trial with large population should be conducted to validate the findings from this study and get an estimate on the sample size.

Future Studies:

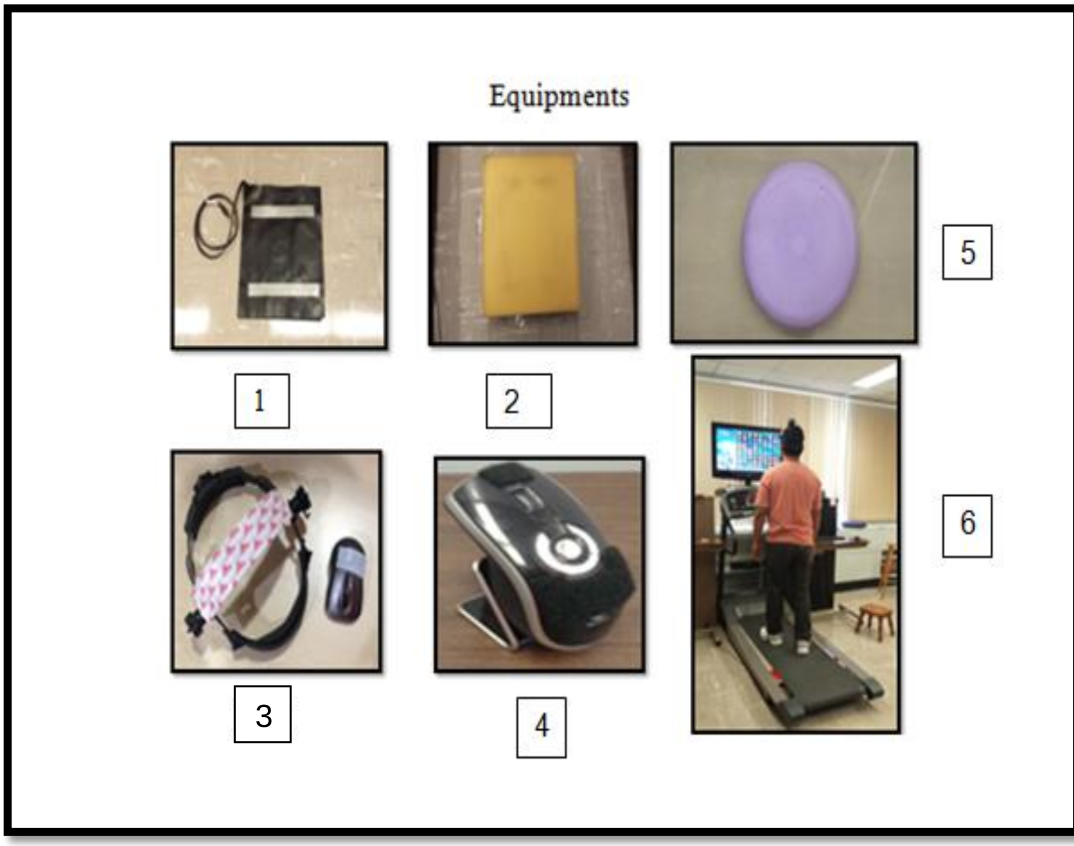
- Day to day activities require dual-tasking, so future studies should conduct researches to train dual task abilities to prevent and reduce the risk of falls.

- Different groups of population of older adults like those who have a history of fall or who do not have a history of fall and with different levels of cognition like dementia and MCI should included to study the effect of the training program.
- Long term follow-up to understand the retention of the effect of the program should be conducted.
- Progressions to unsupervised community training should be conducted.
- Also as further studied should be conducted to study the effect on day to day activities like Berg balance test or Time-up and go test.

Appendix

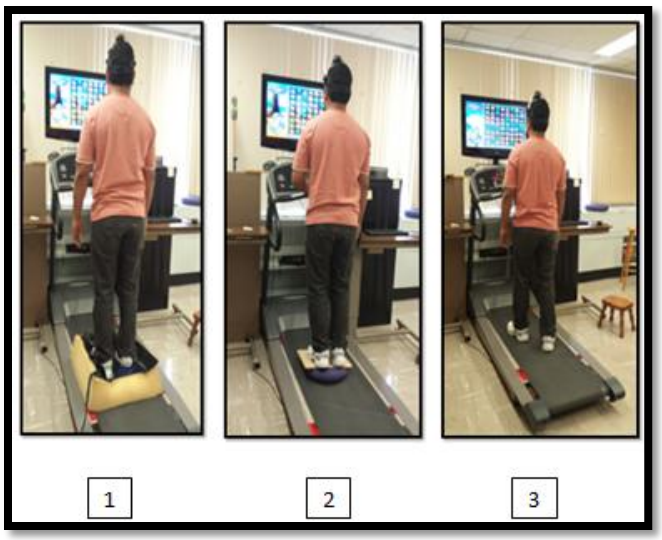
Appendix 1:

Equipment and set up: 1) FSA mat; 2) Sponge; 3) Headband with Velcro; 4) Gyration mouse; 5) Rubber disc and 6) DT-TW



Appendix 2:

Dual-task training while: 1) Standing on sponge; 2) Standing on a rubber disc and 3) Walking on treadmill



Appendix 3:

Qualitative interview questions:

1) Why did you agree to participate in this training program?

2) When you agreed to participate, how did you hope to benefit from the program?

3) What did you think about the difficulty of the exercise?

4) Did you participate in the training program as frequently as you would have liked? Explain?

5) Would you have liked to perform different exercises than the one you did?

6) Did you understand what the games were used for? Explain your answer?

7) Does the game make you feel fully engaged in the session?

8) What were the things about the game you liked and disliked?

9) Which games did you like and did like?

10) Overall, how satisfied were you with the training program? Explain your answer?

11) If you were provided with the right setting, would you continue these exercises?

12) What, if anything, would you suggest to do to improve this training program and approach?

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