

The Influence of Different Mental processes (Cognitive Loads) on Gait: A Study of Dual-task Function

by

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A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba in partial fulfillment of the requirements of the degree

of

MASTERS OF SCIENCE

College of Rehabilitation Sciences

University of Manitoba

Winnipeg

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ABSTRACT

Walking outdoors requires one to deal with a wide range of visual and cognitive perturbations, i.e., multiple object tracking and making timely decisions while ignoring irrelevant information, etc. Using dual-task gait paradigm, the purpose of this thesis was to evaluate the age effects of different types of visuospatial cognitive tasks, i.e. designed cognitive game tasks and commercial computer games on gait and cognitive performances in older adults as compared to the younger adults. A standardized dual-task assessment approach, i.e. objectively evaluating both gait and cognitive performances simultaneously, has potential to be the screening tool to detect gait and cognitive impairments in early stages. Further, evaluating the training value of commercial computer games by comparing them with the designed cognitive games with objective outcome measures will help in developing multimodal dual-task intervention platform to treat and prevent age-related physical and cognitive impairments.

Key words: Aging, Dual-task, Gait, Cognitive impairments, intervention

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ACKNOWLEDGEMENTS

This work would not be accomplished without some amazing people I met who have been a constant source of inspiration and joy in my journey over the past three years. I would like to thank my advisory committee Dr. Barbara Shay and Dr. Jonathan Marotta for their interest and valuable inputs on my thesis. I express my sincere and deepest gratitude to Dr. Tony Szturm, for his support and constant encouragement during my tenure at his lab. I am thankful for his meaningful suggestions and positive criticism, which guided me to complete this work.

I really appreciate all the volunteer participants for their time and participation in this study. Many thanks to my lab colleagues for helping me to collect the data at times, even over the weekends, for making those coffee runs.

This would not be complete without mentioning my loving parents, Asha Nankar and Datta Nankar who provided support and strength during my years at the University of Manitoba. They have always encouraged me to persevere and follow my passions and not be afraid of making mistakes along the way. For this, I will remain eternally grateful.

DEDICATION

I dedicate this thesis to my loving wife Archana Krishnan who has always been a constant source of inspiration for me. This would not have been possible without your unconditional love and trust in me.

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LIST OF ABBREVIATIONS USED

ADL: Activities of Daily Living.
ANOVA: Analysis of Variance
AD: Alzheimer's disease
AP: Antero-Posterior
AQ: Aqua ball
BOS: Base of Support
CGP: Computer game-based platform
COM: Center of Mass
CNS: Central Nervous System
COG: Center of Gravity
COP: Center of Pressure
COV: Coefficient of Variation
CTSIB: Clinical Test of Sensory Interaction and Balance
CHAMPS: Community Healthy Activities Model Program for seniors
DT: Dual-Task
EF: Executive Functions
FES: Fall Efficacy score
FSA: Force Sensory Array
ICC: Intra-class Correlation coefficient
IMU: Inertial Measurement Unit
LOB: Loss of Balance
MCI: Mild Cognitive Impairment
ML: Medio-lateral
MMSE: Mini Mental Status Examination
MCI: Mild Cognitive Impairment
MCTSIB: Modified Community Healthy Activities Model Program for seniors
MDC: Minimal Detectable Change
PWS: Preferred Walking Speed
RMANOVA: Repeated Measures Analysis of Variance
SOT: Sensory Organization Test
SEM: Standard Error of Measurement
SS: Serial Subtraction
SsT: Single Support Time
ST: Stride Time
SW: Step width
SwT: Swing time
TMT: Trail Making Test
TRE: Total Residual Error
TT: Treadmill training
TUG: Timed Up and Go
VM: Visuomotor
VS: Visuospatial
VSCG: Visuospatial cognitive game task

Chapter 1 Introduction

According to the World Health Organization (WHO) 2008, about 2 billion people will be 60 years and older by 2050 [1]. Aging leads to physical decline i.e. gait and balance impairments, and this is accompanied by cognitive problems such as mild cognitive impairments, dementia and Alzheimer's disease. This may lead to serious problems such as falls; causing injuries, disability and dependency in late adulthood. With growing life expectancy, the need for new therapies to treat physical and cognitive decline associated with aging becomes more urgent. Walking safe in an outdoor environment, which becomes increasingly difficult with aging, requires simultaneous control of sensory-motor system along with processing of incoming information using cognitive functions. Currently, research in aging communities is aimed at developing preventive interventions for falls and to enhance mobility by training balance, and walking function. Also, cognitive training (executive functions) which are required for activities of daily living, has become an integral part of health promotion especially in regards to management of dementia.

“Dual-tasking” is an integrated approach combining physical and mental activities, which is employed to train motor and cognitive functions simultaneously. Increasing advances in technology and its low cost lead to popularity of dual-task training programs involving platforms such as Kinect, Wii boards; that requires one to balance on board and play video games by shifting weight or walking on a treadmill while being engaged in activities such as looking at onscreen projection, phenome monitoring, serial subtractions etc. to treat and prevent balance and gait impairment and to some extent enhance cognitive functions.

Using computer based video games Szturm et.al, 2013 developed an interactive platform to train balance/gait and cognitive functions simultaneously [2]. This approach is engaging, provides valuable feedback and breaks the monotony of boring routine physical exercises. Although, how different types of custom cognitive tasks, computer games and their level of complexity affects balance and gait performance in older adults still remains to be explored.

1.1 Literature Review

1.2.1. Age related decline in physical activity & mobility limitations

Aging leads to progressive decline of various bodily functions such as: musculoskeletal strength, level of physical activity, balance and mobility, vision and vestibular function.

Hirvensalo et al. (2000) [3] examined the association of mobility decline and physical inactivity with future risk of disability and mortality in 1109 community dwelling older adults (65-84). Participants were divided into 4 groups based on their level of physical activity (i.e. Active or impaired) and mobility (mobile or sedentary). Results were reported as Odds Ratios ($OR \geq 2$ strong risk factor). Impaired-sedentary men ($OR = 5.21$) and women ($OR = 2.92$) were at higher risk of disability and dependency as compared to an Active mobile group. Also, relative risk (RR) for dependency was 2 times greater in the impaired-active and 3 times in the impaired-sedentary group as compared to the Active mobile group. The authors concluded that mobility impairments are a significant predictor of age related dependency. Also, participants with impaired mobility but moderate level of physical activity were at lower risk of future disability and mortality. Similar findings were observed by Visser et al. 2000 [4]

Aging is often accompanied by a balance impairment, which hinders independent mobility. Maintaining balance requires integration of vision, vestibular and proprioceptive spatial information. Force platforms has been widely used to assess standing balance performance [2, 5-8]. Abrahamova et al. (2008) [5] examined the changes in center of foot pressure (COP) parameters of quiet stance under altered surface conditions and visual status as a function of age. 81 healthy participants were age

stratified into three groups; 34 juniors: (20-40); 20 middle aged: (40-60); 27 seniors: (60-82) years. Participants were tested while standing on fixed and on sponge surfaces under eyes open and eyes closed conditions. A significant decline in balance was observed on the sponge surface with eyes closed in older adults. Similar findings were reported by Swanenberg et al. (2008) and Strang et al. (2011) [7, 8].

Desai et al. (2010) [9] evaluated the Dynamic Balance Assessment (DBA) test protocol using the Sensory Organization Test (SOT) and Clinical Test of Sensory Organization and Balance (CTSIB) to differentiate fallers from non-fallers in older adults. 72 healthy older adults' aged ≥ 65 , were instructed to perform dynamic balance activities under altered visual status and surface conditions. The magnitude of Center of pressure (COP) was measured using a Force Sensory Array (FSA) mat. They observed a significant loss of balance and increased COP excursion more so on a sponge surface as compared to the fixed surface ($p < 0.0001$). Decline in balance performance was significantly greater in elderly fallers, particularly on a sponge surface as compared to non-fallers.

Szturm et al. (2015) [2] examined the effects of dual-task conditions on core balance performance in 30 older adults (aged 60–67 years). Participants performed computerized head tracking and cognitive game tasks (hands free using head pointing movements) while standing on fixed and sponge surfaces. Both balance and cognitive performance were measured simultaneously. Core balance performance was measured as COP excursion; Root Mean Square (RMS), in antero-posterior AP and Medio-lateral ML direction. Under dual-task conditions a significant decline in balance performance; i.e. increase in Root Mean Square of center of foot pressure in AP and ML was observed.

Also, DT Cognitive performance (Success rate) and movement time declined significantly on the sponge surface relative to the fixed surface.

A number of studies have examined the age effect on gait speed and altered gait patterns. Gait speed is a clinically important indicator of health and functional status and a predictor of survival in older adults [10-12]. Burrachio et al. (2010) [13] evaluated gait speed in 206 cognitively intact community dwelling healthy adults, age ≥ 65 . They evaluated gait speed every year and followed up the participants over a period of 20 years. Independent of age effects, participants who later were diagnosed with cognitive impairment had a greater decline of gait speed 0.01meter/second/year compared to the healthy aged over the follow up years. They concluded that along with the physical decline, longitudinal change in gait speed can also, be an indicator of decline in cognitive function.

Hollman et al. (2011) [14] examined the effect of aging on spatiotemporal gait variables in 294 active community dwelling older adults (70-85 years); divided into three age groups (70–74), (75–79) and (80–84). Based on factor analysis, they grouped spatiotemporal gait variables into 3 major factors; Rhythm (temporal gait variables step, swing, stride, stance and single support time), Pace (gait speed, step and stride length), and Variability i.e. co-efficient of variation (COV's) of spatial and temporal variables. Comparison between three age groups revealed that oldest participants walked with a reduced step, swing, stride, stance and single support time. For Pace factor; gait speed, step length and stride length declined as a function of age. The authors concluded that gait speed and spatiotemporal gait variables decline with increasing age resulting in mobility limitations.

Ko et al. (2012) [15] examined the effect of aging on gait characteristics of 190 active adults. They stratified participants in three age groups; middle (32–57; N=27), old (58–78; N=125), and oldest (79–93; N=38). Participants walked on a 10m walkway at their preferred and maximum walking speed. Average gait speed, stride length and stride width was captured (Vicon 3D motion capture system). Significant decline in both the preferred and maximum gait speed was observed in oldest group relative to old and middle group. Average stride length and stride width were also significantly affected in the oldest group as compared to old and middle age adults. Similar findings were reported by two other studies Ostir GV et al. 1998 and Onder G et al. (2005) [16, 17]. Thus, community dwelling seniors are at a higher risk of age related gait impairment, which may lead to institutionalization and an increased mortality rate [12, 18-23].

Callisaya et al. (2010) [24] examined the association of age with gait variability in 411 older adults (60–86 years). Gait assessments were conducted over ground using pressure insoles and ≥ 20 steps were used to obtain gait variables. Age showed moderate association ($r = 0.3-0.39$) with COV Step time variability ($r = 0.30$), Step length ($r = 0.30$), Double support time ($r = 0.30$) and weak association with Step width ($r = 0.20$).

1.2.2 Age-related Decline in Cognitive Functions

Normal physiological aging shows signs of impaired memory and cognitive functions. Cognitive processes particularly “Executive functions” (EF) is an umbrella term that refers to a set of cognitive skills necessary to plan, monitor, and to execute a sequence of goal-directed, complex actions [25]. These functions comprise of working memory, problem solving, initiation, inhibition, mental flexibility, task switching, and attention. “A report by (OECD) 2002 showed that, decline in the cognitive abilities begins at 6th and accelerates during the 8th decade of life” [26].

Hoogendam et al. (2014) [27] studied the association between aging and cognitive functions in 3012 healthy older individuals mean age 71.9(9.7). Cognitive functions were assessed using the following test batteries; Mini Mental Scale Exam (MMSE), Stroop Test, Letter-Digit Substitution Task (LDST), verbal fluency test, 15-word verbal learning test (15-WLT), Design Organization Test (DOT). They observed a strong association between age and decline in specific executive function ($r \geq 0.5$). For every 10 years increase in age, there was a significant decrease in scores on the Stroop task, letter-digit substitution task (LDST), verbal fluency test and design organization test (DOT). They concluded that aging is significantly associated with decline in processing speed, inhibition and visuospatial abilities.

Ojagbemi et al. (2015) [28], examined association between aging and cognitive functions over 2 years in 2149 community dwelling older adults ≥ 65 years. Baseline cognitive functions; short term memory, processing speed, inhibition and mental flexibility were assessed using 10-word learning list and delay recall test, Trail Making Test -A & B, and the MMSE. Follow up assessment conducted at year 2 revealed a

moderate association for 10-word learning list and delay recall test ($R^2 = 32\%$) and for Trial Making Test A & B ($R^2 = 40\%$). Thus, aging leads to decline in memory along with processing speed, inhibition and mental flexibility. Similar findings have been reported by; Ding et al. (2015) and Albert SM et al. (2015) [19, 29]

1.2.3 Epidemiology & Incidence of Fall and Risk factors for fall associated with aging.

Epidemiological studies show that the incidence of fall affects one in three adults over the age of 65 years annually and 50 % of adults after eight decade of life [1, 30-36]. Falls occur for many reasons and the interaction of many risk factors is commonly observed in older adults. This results in injury and disability. Extensively cited work by Tinetti et al. (1988) [37] shows that diverse risk factors for falls such as, gait and balance impairment and impaired cognition are observed in aging communities.

Shin et al. (2009) [38] evaluated the association of level of activities of daily living (ADL) and cognitive status with risk of falling in 335 community dwelling older adults (M=72.87 years). The Korean version of the MMSE, Folstein et al. (1975), was used for the assessment of cognitive status. They observed the following results: 15 % of the participants experienced a fall in the follow up period of one year. This was experienced due to the following reasons; slipping (52.1%), loss of balance (8.3%), tripping (6.3%) and while walking (6.3%). Participants experienced 52 % of falls during indoor walking, where as 41.7% of falls occurred during outdoor walking. Fallers had lower exercise behavior and participated less in activities of daily living. Older adults who scored one unit greater on the ADL scale were 1.02 times more likely to be non-fallers. Thus, as the level of participation in activities of daily living increases, the risk of falls decreases.

Hong et al. (2010) [34] studied the effect of age on fall incidence and its association with cognitive impairment, visual deficit and decreased daily activities in 10,254 community dwelling adults. They were divided into young (45-64 years) and old groups (65-85 years). A MMSE score of less than 23 was defined as cognitively impaired. They observed that the older adult group had a higher rate of falls (6.3%) compared with the younger adult group (4.1%) and with increasing age, the rate of falls was higher, i.e. the rate for participants aged 75 to 79 years was 8.0%. The study also examined the rate of falls requiring treatment, which was observed to be 4.3% more in the older adults than the younger adult group. This was also observed to be increased with age, i.e. participants who were 85 years of age had the highest rate of (6.0%) falls requiring treatment.

Visual input plays an important role in postural control by providing information regarding body orientation and movements [39]. Patino et al. (2010) [40] examined the association between visual impairment and falls in older adults. A total of 3023 older adults were evaluated for central (CVI) and peripheral (PVI) vision impairments. Falls were self-reported at the follow-up visit. Moderate-severe CVI and PVI were strongly associated with falls ($RR= 2.4$), ($RR= 1.5$). One other study by Nagamatsu et al (2013) [41] reported a moderate association ($r = 0.51$) between fall risk with visual attention in older adults. Thus, visual impairments are independent risk factors for falls and should be given due consideration in fall prevention programs.

Odasso et al. (2005) [42] investigated gait velocity as a predictor of adverse health outcomes in 102 community dwelling well-functioning older adults'. Gait speed was assessed by instructing the participants to walk on an 8-10m long hallway at a preferred speed. Gait speed was assessed over 6 steps. At the 2 year follow up they concluded that reduced gait speed is an independent predictor of falls (RR = 5.4).

Studenski et al. (2007) [43] identified that gait variability, defined as a fluctuation in gait variables from one step to the next is an important indicator of impaired mobility in older adults. Greater stance time variability is an independent predictor of future mobility disability [44]. Recent long-term prospective epidemiological studies demonstrated that gait performance, and especially stride-to-stride variability, during dual-tasking (DT) may be a particularly sensitive predictor of falls in older adults [45, 46].

Verghese et al. (2009) [22] examined the association between variability of stride length, cadence, swing time, gait speed and double support time with the incidence of fall rate in 597 older adults. GAITRite carpet was employed to assess spatiotemporal gait parameters, which were calculated over 5 steps. Decline in the gait speed was moderately associated with the increased risk of falling (RR = 1.078). Also, Stride length variability (RR = 1.128) and swing time variability (RR = 1.011), were moderately associated with increased risk of falling. Similar findings were reported by Hausdorff et al. (2001) [46]

Age associated cognitive decline has also been considered as a notable health issue and an independent risk factor for fall [47, 48]. Future risk of falls, fear of falls and depression are the deleterious after effects of falls [31, 46, 49]. Fall related injuries has a

significant economic cost, and causes burden on caregivers and health care system [35, 50].

1.2.4 Simultaneous Decline in Physical Abilities and Cognitive Functions Associated with Aging.

Physical and cognitive impairment often co-exists in the aging population, and they result in an increased risk of mobility limitation and falls. Dual-task approach has become popular in recent years to evaluate the effect of aging on gait and cognition simultaneously.

Ijmkar et al. (2012) [51] examined association between age, gait variability and cognition under dual-task walking conditions in older adults; 15 dementia patients, (MMSE score ≤ 16), 14 age matched healthy adults, and 12 relatively younger elderly. Participants were instructed to speak out as many words as possible for a given specific letter (letter fluency). Walking trials were conducted over a 10m walkway and 24 non-consecutive steps were analyzed to obtain gait variables such as gait speed and average and co-efficient of stride time (ST). Executive function was assessed using the Trial Making Test - A & B, letter fluency and category fluency (naming animals). Under DT conditions, they observed a significant decline in average gait speed and COV of Stride time, category fluency in all three groups. This effect was more pronounced in the dementia group ($p < 0.001$) relative to cognitively intact young and old control group. They observed a strong association ($r = 0.7$) between gait speed and COV-ST with global

MMSE and specific cognitive functions (Trial Making Test - A & B, letter and category fluency).

Martin et al. (2013) [52] examined the association between both gait speed and gait variability with executive functions in 422 older adults age $M = 72(7.1)$ years. Neuropsychological tests were used to assess cognitive functions. Quantitative gait assessment included the following gait variables: Average and COV, gait speed, step time (ST), step length (SL), step width and double support phase (DSP). Over ground assessment (GAITRite Systems) for 5 continuous steps, 24 strides over multiple trials were included in the final analysis. Results showed that speed of processing and response inhibition were strongly associated with gait speed ($RR = 2.42$; $RR = 1.57$; respectively). Also, speed of processing was strongly associated with DSP ($RR = 1.13$).

Mielke et al. (2015) [53] examined the association between gait speed and cognition in 1,158 community dwelling healthy older adults (70-89 years). Cognitive functions were measured using Trial Making Test A & B and Digit Symbol Substitution test. A strong ($r = 0.5-0.7$) association between gait speed and executive functions (inhibition, mental flexibility, attention and memory) was reported at baseline and at 1 year follow up. Similar findings were reported by Verghese et al. (2013), Odasso et al. (2013) [54, 55].

The above studies show that falls are multifactorial in nature. Major risk factors for falls are balance, gait, and cognitive impairments [5, 7-9, 15, 18, 20, 42, 43, 51, 56, 57]. Co-existence of physical impairment such as gait and balance decrement along with cognitive issues such as mild cognitive impairment has a common occurrence in aging

communities [51-53, 58]. These problems are interrelated, and compounds the occurrence of falls, mobility limitations and incident disability in aging communities [34, 38].

1.3 Aging & Dual-task Ability

The “Dual-task” approach is an experimental procedure that requires an individual to perform two tasks simultaneously; a motor task usually balance or walking along with a concurrent cognitive task. Dual-tasking is an absolute prerequisite for day-to-day life; for example, walking while holding a coffee mug, crossing street or navigating on an uneven surface etc. This activity of daily living requires one to timely process information, avoid distractions, make decisions and produce an appropriate response. Dual-tasking has become a popular approach in recent years to assess the effect of age and cognitive decline on gait, and to discriminate fallers from non-fallers [59, 60]. The underlying assumptions of dual-tasks are that resources required for information processing are limited and if shared by two tasks may lead to decrement in performance of one or both the tasks together [59, 61, 62].

Many different cognitive tasks have been used in DT walking studies. These include Reaction time (Visuomotor tasks), Semantic memory (Verbal and category fluency task), Discrimination and decision making (Stroop), immediate recall (Brooks’s tasks) and Working memory (n-Back) [63]. A majority of these studies have been conducted while walking over ground and the 5-meter long GAITRite carpet is used to quantify spatiotemporal gait variables. In this case, only 4-5 consecutive steps are recorded. The participant’s stops turn and repeat the short walk to obtain 10-25 steps. However, it should be noted that this method gives the participant’s a time window to get familiar with the cognitive tasks and rehearse their responses [55, 64-66]

A significant reduction in gait speed is the primary findings of the dual-task studies [55, 64-68]. Gait speed decline is greater in older adults (60-85 years) than young adults (20-30 years) [61, 67]. Also, studies involving cognition observed i.e. MCI, Dementia or Alzheimer's demonstrate a significant reduction in gait speed during DT when compared with age-matched healthy adults [51]. This finding may be due to fear of falls while dual-tasking. Many of these studies use stride time variability, or variability (COV) of other spatiotemporal gait variables as an outcome measure for dual-task gait performance. Gait variability is measured as co-efficient of variation, which is defined as step-to-step fluctuation during the gait is used as an index of "gait stability" as opposed to rhythm [64, 65, 69]. In light of the fact that gait speed changes significantly between walk alone condition and during the DT walk, shows that gait speed has a significant effect on COV of all gait variables [45, 61, 65, 70]. Thus, gait speed has a confounding effect on gait variables during dual-tasking.

At present, treadmills have become a "platform of choice" for DT studies; to avoid the confounding effect of gait speed. Szturm et al. (2013) [71] developed and validated the Computer game-based platform (CGP). Maharjan and Szturm (2013) [72] examined the effect of dual-tasking on gait and cognitive performance in 30 young adults. A treadmill was instrumented with a Force Sensor Array (Vista Medical mat), this custom instrumentation is similar to the GAITRite carpet and allows comprehensive gait analysis (Maharjan et al. 2013 used Pressure insoles). Treadmill gait analysis is an attractive alternative as it needs less space and safety features such as side rails and safety harness. Uninterrupted assessment with hundreds of steps is an added advantage. This was coupled with a computerized cognitive game [71] (outcome measures success rate,

% error, response time and movement time) with different complex levels targeting visuospatial abilities along with executive cognitive functions such as processing speed, inhibition etc.). A custom air mouse was mounted on a head band and these games were played using head pointing movements (up-down & side to side) under single and DT (while walking). They observed a significant decline in average step length, step time along with increase in COV swing time and step width under DT conditions.

A limited number of studies have looked at how different cognitive tasks affect the gait performance. Comparing different types of cognitive tasks may provide insight into the nature of the cognitive processes required for the control of dual-task gait.

Xingda et al. (2014) [73] examined the effect of different cognitive tasks on gait characteristics in 12 young adults. During treadmill walking, participants performed the Brooks spatial task (immediate recall task requires one to fill the 3 by 3 number grid), random digit generation (randomly enumerate a three-digit number) and serial subtraction by seven's (7's). Gait variables, Average and COV of step length (SL), step width (SW) and step time (ST) were determined over 150 steps (Motion Analysis Eagle System, USA). DT had a significant effect on average (ST) and COV (SW) for all the 3 cognitive tasks compared to baseline walk. DT Brooks task had a greater effect for COV (SW) and ST relative to random digit generation and counting backward task. The authors concluded that cognitive task involving visuospatial attention (Brooks' visuospatial task) affects gait more when compared to the working memory task i.e. random digit generation and serial seven's.

Wrightson et al. (2015) [74] examined the effect of different cognitive tasks on dual-task gait in 22 healthy young adults during treadmill walking. Participants walked while performing serial subtraction by 7's from a given random 3-digit number and an n-back immediate recall task which requires one to match the number presented (n) in this case 2 steps previously. Stride time variability (STV) was obtained from 10 consecutive steps using inertial motion unit L5 level (APDM, Portland, USA). Significant decrease in STV was observed under influence of DT Serial 7's and 2-back task as compared to baseline walk. It should be noted that as serial sevens and 2-back task require completely different sets of cognitive functions- working memory for serial sevens versus, short term episodic memory for the 2-back task. However, the magnitude of decrement in stride time variability for both the tasks during DT was not significantly different.

1.2.5 Digital Games: A Tool for Physical & Cognitive Training

Current scientific literature has shown that computer games have the potential to prevent incident disability and promote active lifestyle in aging population. “Exergames” is an emerging trend that couple’s physical exercises with computer games. A number of studies have used pressure mats, Wii, Kinect or more advanced Virtual reality systems to improve standing balance and aerobic fitness in older adults [75-81]

Szturm et al. (2011) [82] conducted a study in 30 community dwelling healthy ($MMSE \geq 26$) older adults. Participants were assigned to control group and experimental group to examine the benefits of physical therapy using an interactive video game. The experimental group received a program of dynamic balance exercises coupled with the video game, while the control group received the typical rehabilitation program that involved strength training and balance exercises. Both groups improved with training, and there was a greater improvement in Bergs Balance Score ($p < .001$), Loss of Balance counts ($P < .007$), and Activities-Specific Balance Confidence Scale ABC ($p < .02$) in the experimental group who received the game-based balance exercise program compared to the control group. From this study we can conclude that, gait performance can be improved by administering programs that involve walking.

Merriman et al. (2015) [83] examined the effect of balance training using the Wii balance program in 76 healthy and fall-prone older adults MMSE<23. The participants were randomized to an experimental group (Wii balance training) or a control passive group. Primary outcome measures for balance were Bergs Balance Score, Activities-Specific Balance Confidence Scale, magnitude of COP excursion (mean velocity) and Fall Efficacy Score (FES). Post intervention, a significant improvement in Bergs Balance Score, Activities-Specific Balance Confidence Scale and decrease in COP mean velocity was observed in the experimental group as compared to the passive control group. A moderate intervention effect was observed in the Activities-Specific Balance Confidence Scale and Bergs Balance Score ($d > .46$). Also, the FES score declined significantly in the experimental group relative to the control group. They concluded that balance training using Wii board is an effective medium for preventing falls in older adults. Other studies have presented similar results Borghese et al. (2014) [84]

The balance games presented above were exergames with very low level or simple cognitive tasks such as catching a ball or moving to avoid being hit by a ball, in order to produce movement and thus attempt to improve balance control. The movements associated with these game controllers are slow and gross movements therefore balance costs are very limited. This narrows the scope of such platforms for age related physical and cognitive remediation.

Cognitive training using a computer based video game aims at enhancing attention, inhibition, perceptual skills, visuospatial abilities and improve decision making skills [85-87]. A number of studies have examined effects of game-based cognitive training on executive function [87-90].

Nouchi et al. (2012) [90] examined the effect of a brain training regime using different cognitive games in 32 active older adults who were randomized to an experimental (Brain age multiple platform games) or active control group (Tetris tile-matching puzzle video game). Primary outcome measures involved neuropsychological tests evaluating different domains of cognitive function. (Effect size reported as eta square $\eta^2 \geq .01$ small, ≥ 0.6 medium, and ≥ 0.14 large). Both groups showed improvement for processing speed and attention. This effect was greater in the experimental group for mental flexibility (Trial Making Test-B (0.14)), Attention (D-CAT (0.6) and Processing speed (Cd (0.2) and SS (0.12) relative to the active control group. They concluded computer games can be used to train specific executive functions in older adults. Similar findings were observed by Patterson et al. (2013) [92]

Typically, these computer games are played while sitting in front of a computer screen and focus only on improving cognitive functions. A motivational blend of exercises using computer games for older adults can be an effective strategy for health promotion in aging communities. Growing appreciation of the interdependence of cognitive and balance control processes has led to search for multimodal interventions combining motor and cognitive training for improving gait and preventing falls [79, 82, 91]. Diamond (2015) [92] reviewed different DT interventions and concluded that

interventions challenging diverse motor and cognitive skills simultaneously are more effective than task specific strategies.

Mirelman et al. (2010) [90] examined the effectiveness of Treadmill training (TT) coupled with Virtual reality (VR) against TT to improve mobility in 20 older adults with Moderate Parkinson's disease (PD) (Hoehn and Yahr Stage II–III). Post intervention, both groups showed improvement in gait speed, stride length and a decrease in stride time was observed. The TT+VR group showed significant improvement in dual-task ability (during obstacle negotiation) relative to the TT group. Compared to the active control group, the experimental group shows improved scores on Trial Making Test - A & B and serial subtraction. The authors concluded that multimodal approach such as TT+VR have potential to improve gait, balance and to some extent, cognitive functions in PD

A pilot trial was conducted at a community fitness center (Reh-fit center, WPG, Canada) by Alhasani & Nayak et al. (2015) [91] The investigators compared the effect of a DT treadmill walking program and a DT recumbent cycle program on improving DT balance, gait performance, gaze and cognition in 22, community dwelling older adults. Training session were conducted for 8 weeks and composed of playing commercial cognitive games ([www.bigfish games.com](http://www.bigfishgames.com)) using head pointing movements while treadmill walking or recumbent cycling. Post intervention, both groups showed a significant improvement in DT balance and gaze performance but the DT treadmill group showed a greater improvement. Also, the DT treadmill walking group showed a significant improvement in DT walking performance. Trial Making Test scores showed a significant improvement post treatment and there was a significant between group effects with the DT treadmill walking group showing greater improvements than the DT

recumbent cycle group. The authors concluded that dual-task interventions to improve age related physical and cognitive decline are feasible, and can be successfully conducted in community settings.

The above section highlights current scientific evidence and the potential benefits of computer game based therapies for the treatment and prevention of age-related motor and cognitive deterioration. Further studies should be directed to explore the components, which cause learning effects. Research must be fostered in diverse populations employing reliable methods and robust outcome measures as these interventions have potential to go beyond the health sector.

Chapter 2 Summary

Our review of the relevant literature views gait as a complex task, relying on motor and sensory systems and simultaneously engaging cognitive functions to successfully deal with moment-to-moment real life situations such as, obstacles avoidance, navigation, distractions etc. Aging is commonly accompanied by progressive decline in the level of physical activity [3, 4, 93-95], muscular strength [15-17, 21, 96] and balance [5, 7-9, 97, 98]. “Falls” are a major concern in aging communities; different studies have identified balance and gait impairments [8, 9, 13, 24, 43, 44, 46, 49, 99-101], and progressive cognitive decline as a major risk factor for falls in older adults [13, 19, 27-29, 56, 102]. Visual impairments and visuo-spatial abilities are also considered an important factor for falls [40, 41, 103]. Falls in old age result in an incident disability, mobility limitation and dependency [19, 30, 36]. Recent long-term prospective epidemiological studies demonstrated that gait performance, and especially stride-to-stride variability, during DT may be a particularly sensitive predictor of falls in older adults [46, 61, 101]. Increasing evidence from clinical practice, epidemiological studies, and clinical trials show that balance control, gait health, and cognition are interrelated in older adults [6, 51, 52, 54, 57]. This necessitates studying aging, gait and cognitive decline simultaneously.

Dual-task paradigms permit detection of both gait and cognitive deficits and can differentiate fallers from non-fallers, which under single task condition of walking alone may otherwise remain undetected [59, 60]. Most DT walking studies use over ground walking, however there are a number of problems associated with this method. Gait speed is not controlled, recording devices such as the GAITRite carpet are used to quantify spatiotemporal gait variables, which are assessed briefly over 5 meters for 5 or

fewer steps, and there is a limited choice of cognitive tasks one can use [55, 64-66, 69]. In addition, coefficient of variation, the most commonly used outcome measure needs to be assessed over 20 - 40 consecutive steps as a reliable indicator of gait performance. A treadmill instrumented with a pressure mapping system similar to the GAITRite and a standard LED display allows easy presentation of many different computerized cognitive task and holds promise for future DT studies [2]. Using a head mounted motion mouse, one can also have a real-time interaction with the cognitive game tasks during treadmill walking [71, 82, 91, 104].

Currently, different platforms such as Wii, Kinect etc. [75-78] are being used to train balance in older adults. These platforms have poor progression of skills in both cognitive and motor domains. Cognitive remediation using computer games is a feasible approach in older adults [82, 86, 87, 89, 105]. Multimodal interventions targeting diverse motor and cognitive skills simultaneously has a potential to treat and prevent age related physical and cognitive decline [79, 92]. A computer game based treadmill platform has been developed for this purpose [2]. Studies have shown that this approach is feasible and its scope can be extended beyond clinical settings to community centers [79, 91, 106]. At present only few studies describe how different types of cognitive tasks i.e. often the cognitive tasks are not computer games or for that matter even computer tasks i.e. serial sevens, animal enumeration etc. affects gait performance. Thus, establishing a classification system of how different commercial and designed cognitive games affect gait performance will aide in categorizing different computer games.

The influence of different cognitive tasks on gait performance is the prime highlights of DT studies. As shown by Szturm et al. [2, 104] computerized cognitive

tasks coupled with treadmill has an added value as, it allows comparison between different cognitive tasks under standard testing conditions [2, 72, 104]. These studies attempt to provide knowledge about how different cognitive processes contribute to the dual-task effects on gait characteristics. Better understanding of the interaction between gait and cognitive functions would benefit both researchers and professionals to plan appropriate interventional trials and informed clinical decision-making [63]. Thus, gait based task classification method can be a basis for interventions aimed at improving dual-task walking abilities and fall prevention programs.

Further, this thesis has been divided into two manuscripts; the first manuscript evaluates the age effects of visuomotor and visuospatial executive game task on dual-task performance, i.e. both gait and cognitive performance during the treadmill walking. The second manuscript compares the age effects on dual-task walking while interacting with different visuospatial cognitive tasks, i.e. designed custom games and commercial computer games.

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Chapter 3 The Interacting Effects of Different Types of Visuospatial Cognitive Task: Discriminating Age Effects, Dual-Task and Prioritization.

3.1 Abstract

Background: The dual-task (DT) methodology is usually applied to evaluate the effects of the cognitive task on the gait. A majority of dual-task gait studies employ; serial 7s, speech or auditory Stroop, as a secondary cognitive task. However, only a few DT studies have evaluated the effect of age on the executive functions involving visuospatial processing. The objective of this study was to examine the influence that visuomotor and visuospatial executive cognitive tasks have on gait function during dual-task treadmill walking in young (20-35) as compared to older adults (70-85). Conversely to examine the influence that physical demands have on executive functions involving visuospatial processing.

Method: Twenty-five active young (Age $26 \pm (6.1)$ & 25 older adults (Age $76 \pm (3.9)$, (MMSE ≥ 25) concurrently performed two types of visuospatial cognitive tasks while walking at a constant treadmill speed of (0.7m/s). The first, a visuomotor tracking task (VM) which required continuous visual attention and head rotation and secondly, a visuospatial cognitive game task (VSCG), which required visual search and cognitive inhibition. Performances of the visuospatial tasks were evaluated in standing (single-task condition) and during treadmill walking (DT condition). The average and coefficient of variation of spatiotemporal gait variables was assessed over 40 consecutive steps during walk alone and different dual-task conditions.

Results: Visuomotor dual-task had a significant effect on gait variables in younger adults but no effect in older adults. However, VM performance in standing was significantly less (2-3 times) in the older age group as compared to the young. The VSCG dual-task had a significant effect on the gait variables in older adults but no effect in the younger

group. Success rate decreased during DT walking, but only in older adults. Response time increased during DT walking in the younger age group, but not for older adults. To note, the response time in the older age group was nearly twice as that of the younger group when tested in standing.

Conclusion: Different types and complex levels of visuospatial tasks affect the gait and executive cognitive performance in a different manner in both younger and older age groups. It is suggested that older adults adopted a different strategy to reduce the attentional load during dual-task walking. DT gait assessment using visuospatial executive cognitive tasks in older adults may reveal significant information about their interaction with the external environment.

Key words: Dual task assessments, aging, gait, executive functions, computer game based platform

3.1.1 Background

Safe, independent community walking outdoors require both mobility skills and cognitive flexibility to attend to a range of environmental demands, threats to balance and for navigation. Gait and cognitive impairments common to aging often coexist and are prognostic of future adverse health events [1]

A growing body of evidence reports that abilities that commonly show impairment with age are those associated with dual-task walking in which two tasks have to be maintained and implemented in the face of divided attention, distractions and increasing memory loads. For example, gait variability, specifically stride time variability [2] increases during dual-tasking in older as well as cognitively impaired population and may be a sensitive predictor of falls in older adults [3-5].

In addition, older adults and cognitively impaired individuals show a decreased dual-task ability compared to age matched healthy adults [2], Studies have put forth the affirmation that difficulty in the ability [6]. to assign attention to each task, the information processing speed required and the need for supervisory control [6] contributes to increased fall risks in older adults. Recent studies provide evidence that older adults who simultaneously perform physical and cognitive training experience greater improvements in executive cognitive functioning, compared to those performing cognitive training alone [7-9].

Most DT gait studies performed over ground show a decreased walking speed, thus; often there is a prioritization of the secondary cognitive task observed over the primary gait task. Reduced gait speed is commonly observed in many older adults and a

slowing of gait speed is also observed when negotiating obstacles and irregular or unpredictable terrains, i.e. threats to balance. Many DT gait studies examine how cognitive demands affect gait rhythm or stability, i.e. spatiotemporal gait variables or analysis of the trunk linear acceleration [10]. However, gait speed is a confounding variable as spatiotemporal gait variables and trunk motion are sensitive to changes in gait speed [11]. Overground DT walking studies use instrumented walkways, which record only 3-6 steps [13]. This method, may reliably measure gait speed, but is not sufficient for [14] measures of gait variability or periodicity, particularly during dual-task walking [12,13]. Further, completed and assessed during the short time period to walk [16] over a few meters. Most commonly, DT assessment paradigms have utilized general cognitive tasks, such as; walking while talking, verbal fluency, serial subtraction (3's or 7's) or auditory Stroop that are typically only assessed qualitatively, do not involve visuospatial processing, and are limited in what individual brain areas are recruited [14,15]. Processing of visual spatial orientation cues, object location as well as for navigation are important aspects of balance and locomotor skills [19]. Dual-task walking studies who have used visual tasks such as Stroop test, go-no-go test or flankers have only evaluated response time, which only, provides information about the processing speed and not accuracy. To overcome these limitations, Szturm and colleagues developed and validated a computer game-based platform (CGP) . It consists of; a) treadmill instrumented with a pressure mat to measure spatiotemporal gait variables during walking at a constant speed and b) motion air mouse Gyration Inc. This when coupled with digital media can be employed to study the effects of visuospatial task (executive cognitive functions) on dual-task performance in older adults as compared to the younger.

Note: Previously this same platform was known as Treadmill rehabilitation platform in submitted theses and published journal articles. From now onwards this platform will be known as Computer game-based platform (CGP)

The objective of this study was to examine the influence that targeted cognitive tasks have on gait performance during dual-task treadmill walking conditions in young (20-35 years) as compared the older adults (70-85 years) and vice-a-versa to examine the influence that physical demands have on cognitive performance.

Participants walked on a treadmill at a fixed speed 0.7 m/s while viewing a computer monitor and interacting with different types of standardized visuomotor and visuospatial cognitive tasks.

This study addressed four primary hypotheses, which are as follows;

1. Increased cognitive loads (single to DT walking) will have a significant effect on gait performance measures in both older and young adults.
2. Dual-task cost of the gait performance measures will be significantly greater for older adults as compared to younger adults.
3. Dual-task cost of the gait performance measures while performing the cognitive tasks will be significantly greater than the visuomotor tasks in both age groups.
4. Increased physical demands (walking versus standing) will have a greater influence on visuomotor and cognitive task performance measures in older adults as compared to younger adults.

A blended analysis of gait and different types of standardized visuospatial cognitive tasks, will contribute to a better understanding of the functional consequences of a decline in physical and mental skills with age and in the early stages of disease, and

this will help in making choices for prevention, treatments, and lifestyle decisions.

Improved methods of screening and fall risk assessment are important because continued difficulties and injuries will have a sizable impact on this very large population.

3.1.2 Methods

Study design: Two-group experimental study.

Ethics: The Institutional Review Board at University of Manitoba approved this study HREB 2014:330. The old group data for the gait and cognitive outcomes reported herein are a subset of another study HREB 2014:293, which were conducted using identical platform [20]

Recruitment and Participants:

Twenty-five older adults volunteered (14 females), Mean age 76 (3.9) years, (range 72-83 years) who attended the Reh-Fit Centre in Winnipeg, MB for recreational exercise. a) The participants were living independently in the community and were able to walk outside without any walking aids for 400, b) had only one fall in the previous year, c) can speak English, and d) MMSE score greater than 25/30. Exclusion criteria Self-reported diagnosis or history of a) stroke, traumatic brain injury or other neurological disorders such as Parkinson's disease and Vestibular disorders., b) cardiac disease who did not receive clearance from their physician to take part, and c) muscular-skeletal injuries or orthopedic diseases such as acute lower back or lower extremity pain, peripheral neuropathy, advanced hip/knee arthritis. A recent medical illness that would affect their balance or ability to walk for a period of at least 6 minutes. In addition, Participants with cardiac disease who a) have not completed cardiac rehab; b) Are less than six months

past the completion of cardiac rehab. In addition, 25 active adults Mean age 26 (6.1) (range 20-35 years), (9 females) was recruited from the student community at the University of Manitoba, Canada who participated in fitness and sports activities on a regular basis. Volunteers were screened for any exclusion criteria; history of neurological or musculoskeletal injuries, any recent history of sport related injury. Prior to testing, each participant from the old group completed the Mini Mental test MMSE, 6-minute walk test (6MWT) on a 300-meter track, and the average walking speed was determined over a 25-meter distance. This was not done for the healthy cognitively intact young adults. All participants provided consent before participating in the study.

3.1.3 Computer Game Tasks

A custom computer application [20,21] with the following two assessment modules was used for this study: (a) a visuomotor (head tracking) module and (b) a cognitive game

Visuomotor Tasks: The goal is to align two objects. One object (circle) is computer controlled and moved horizontally (left-right) on a computer display for 20 cycles at a predetermined frequency (0.5Hz) and amplitude (70% of monitor width). The second object (square) is slaved to head rotation using a head-mounted motion mouse [16]. The goal of the task is to maintain an overlap of the two objects for 45 seconds. The computer application generates a logged data file to record the coordinates of the circle (target) and square (head rotation) at 100 Hz, which is used for offline analysis of gaze performance. Participants were examined at two level horizontal (VM-H) in the transverse plane and vertical visuomotor tracking (VM-V) in the sagittal plane.

2. Custom visuospatial executive cognitive tasks: The goal was to move a paddle (the game sprite) to interact with moving game objects. For this purpose, hands-free head rotation via the motion mouse was used to move the game sprite (paddle) and catch the target objects while avoiding distractor objects. The software presents moving target objects appearing at random locations on the monitor. In response to each “game event” (target appearance) the client produces a short duration ramp movement (0.5 to 1.5s) to catch the moving target for 30 game events.

Levels of game task played for 60 seconds;

- a) Target plus one distractor diagonal trajectory of both target and the distractor (VSCG-G), and
- b) Target plus one distractor with horizontal trajectory (VSCG-V). The task settings, i.e. the number of events and event interval duration (1.5 s) were maintained constant for both age groups.

The game program; a) indexes the “times” for the appearance and disappearance of each game object, b) logs the coordinates of the game objects and paddle (client’s movements) at a rate of 100 Hz response

3.1.4 Gait evaluation

Gait evaluation was done on a standard treadmill (Sports Art Fitness Ltd) at 0-degree inclination, which was instrumented with a force sensor mat (Vista Medicals Ltd, Winnipeg) to record each foot contact and center of foot pressure (COP) [16,17].

3.1.5 Testing protocol

All testing was done in a controlled lab-based environment over one visit, which lasted for an hour. Participants stood on a treadmill at a viewing distance of 100 cm from an 80 cm LED computer monitor. A series of standardized computer task were performed while treadmill walking. The testing protocol was demonstrated to the participants, and they were given a practice trial to become familiar with visuomotor (VM) and visuospatial cognitive game tasks (VSCG)

Participants walked on the treadmill for 10 minutes for acclimation before testing was initiated. The single task condition, walk only (WO) and performing the visuomotor (VM) and visuospatial executive cognitive game task (VSCG) in standing was conducted before the DT conditions (VM dual-task and VSCG dual-task). All dual-task tests were conducted at a fixed treadmill speed of 0.7m/s in both groups.

The DT tests were done in 2 blocks. Block one comprised of visuomotor tasks, horizontal head rotation (VM-H); and vertical head rotation (VM-V). Block two consisted of the visuospatial cognitive game task, target plus one distractor horizontal trajectory (VSCG-V), and cognitive game 2, Target plus one distractor, diagonal trajectory (VSCG-G). Adequate rest period (2 minutes) was provided between the tests to prevent the overflow effect.

The treadmill walking tasks were difficult when performing the concurrent game tasks, particularly for the older adults. The treadmill was equipped with safety side rails in easy reach, and participants were fitted with a safety harness secured above to a support system. In addition, during all tests, a physical therapist stood behind the participants to provide assistance if required.

3.1.6 Data Processing

Spatiotemporal gait variables

Figure 3.5.1C shows method for extracting the gait variables from COP signal of the pressure mat. The average and coefficient of variation (COV) of the following variables were determined for right and left foot; a) Step length (SL), (b) Stride time (ST), (c) Swing time (SwT), and (d) Single support times (SsT). Since, statistical analysis demonstrated no substantial difference in means of right and left gait variables, only the right side gait variables are reported in the analysis. Gait was evaluated over 40 steps for all dual-task walking conditions.

Visuomotor Performance

Figure 3.6.2A. Shows synchronous plots of the target motion (circle) and user 's head rotation (square) for a typical visuomotor task.

The Total residual error (TRE) was determined by computing the difference between the trajectories of the target and head cursor motions.

- a) The movement amplitudes from right to left and left to right or top to bottom and bottom to top were computed for each cycle. The Amplitude variability, a measure of movement consistency over 20 cycles was then determined as standard deviation normalized by mean for all the cycles over 45 s. Amplitude variability showed a high (Pearson $r = 0.98$) correlation and hence, for both groups, i.e. normative population, we presented results for only the right side.

The first two cycles of the visuomotor tracking tasks were excluded to allow the participants' time to acquire the moving target and begin tracking.

Cognitive Performance Measures

Figure 3.6.2B. Presents overlay trajectories of individual head pointing movements for all rightward game events obtained from one game session. Each game event was 1.5 seconds in duration from target appearance to target disappearance. For a detailed description of the game movement segmentation and analysis of the individual contextual game, events see [16,18]. As illustrated in Figure 3.6.2C, the following variables, averaged over all rightward game movements were determined; (a) average movement time; i.e., the time from target appearance to start the game sprite (paddle) movement, b) success rate was also determined as the percentage of target objects that were caught, and c) movement variation is total variance in movement throughout different game trajectories. MATLAB (The Math Works, Natick, MA, version 2010a) was used to compute the outcome measures for the both Visuomotor and visuospatial executive cognitive game tasks.

Dual task cost (DTC) was also computed for both average and COV gait variables for between group comparison using the formula; $DTC [\%] = 100 * (\text{single-task score} - \text{dual-task score}) / \text{single-task score}$. It is magnitude of the change observed for different gait variables from single to dual task. A higher dual task cost signifies a substantial decline and or worsening in performance during the dual task test as compared to the single task.

3.1.7 Statistical analyses

Descriptive statistics, including means, standard deviations, frequencies, and percentages, were used to describe demographic variables Table 3.5.1. The normal distribution of the data was assessed using the Shapiro-Wilks test ($n < 50$) along with measures of skewness and Kurtosis. Preliminary analyses of our data showed that the assumptions of sphericity (Mauchly's test) was violated for most of the gait variables for the older group, hence, non-parametric procedures were used for data analysis.

Baseline between-group (i.e. young versus old) comparison for gait and cognitive performances were conducted using a Mann-Whitney test for spatiotemporal gait variables.

To test our first hypothesis, we conducted Friedman's ANOVA to test the effect of different dual-task conditions (within group comparison) on spatiotemporal gait variables in both groups young and old separately. a) Visuomotor tasks were compared with Walk alone (WO, VM-H and VM-V) b) Further; the visuospatial executive cognitive game tasks were compared with Walk alone (WO, VSCG-G, VSCG-V). The post hoc pair wise comparison was conducted for significant findings using the Wilcoxon signed rank test (WSRT) [19] 2) To test the second hypothesis, a Mann-Whitney test was conducted to observe the effect of age for different task conditions on the gait variables, i.e. both AVG and COV [19]. For this purpose, we computed Dual-task Cost (DTC) using the formula, **$ST-DT/ST*100$** [20] and further, between group comparison was made. 3) The third hypothesis was tested using a Friedman's comparison between different types of visuospatial tasks using the dual-task cost as the outcome measure. This was performed separately for both age groups. The visuomotor and cognitive game performance

measures satisfied the assumptions of normality hence, further analysis was conducted using a parametric test. Baseline comparison using the Independent Sample T-test 4) For our final hypothesis, to examine the effects of physical demands, i.e. DT walk on cognitive performance in both groups we conducted, a Two-way repeated measures ANOVA on visuomotor (only VM-H) and cognitive game (only VSCG-G) performance measures separately (21). The significance level was $\alpha=0.05$. All statistical analysis was conducted using SPSS v22.0

3.2 Results

Seven out of the 25 older participants could not perform the VM dual-task without holding onto to the treadmill side rails. Therefore, the sample size for the older group was 17 for VM dual-task and 25 for VSCG dual-task.

3.2.1 Baseline between-group comparison of gait and cognitive performance measures

The group medians and Interquartile range (IQR) of gait variables for WO are presented in Fig 3.5.3 (average values) and Figure 3.5.4 (COV values). For all average gait variables, older adults showed significantly lower; ST, $z = 2.3$, $p < 0.02$, SwT, $z = 2.1$, $p < 0.03$ and SsT, $z = 2.5$, $p < 0.01$, as compared to younger adults. In addition, COV's for all the gait variables was almost twice in older adults SL, $z = 3.2$, $p < 0.001$, ST, $z = 3.3$, $p < 0.001$, SwT, $z = 3.1$, $p < 0.001$ and, SsT, $z = 3.2$, $p < 0.001$.

The group means and standard error of the means (SEM) for the visuomotor performance measures are presented in figure 3.6.5A. Total residual error ($t_{49} = 9.5$, $p < 0.01$) and amplitude variability was ($t_{49} = 7.7$, $p < 0.01$) significantly greater in older age group compared to younger age group. Also, the baseline Cognitive game performance measures (Figure 3.6.5B) Average movement time was significantly greater, ($t_{49} = 6.2$, $p < 0.01$) and Success Rate was significantly lower, $t_{49} = 2.2$, $p < 0.04$ in older adults as compared to younger adults. No age difference observed for Movement variance, $p > 0.05$

3.2.2 *Dual-task effects on gait variables* Statistical results (Friedman ANOVA) of the effect of task conditions on gait variables are presented in Table 3.5.2 along with the medians and Inter-quartile ranges (IQR) in Figure 3.6.3 (average values) and Figure 4 (COV values). Further analysis was performed to determine which DT tasks were

significantly different than the walk alone condition. The results, i.e., χ^2 - statistic and p-values for each significant pair wise comparison are presented in Table 3.5.3. The VM dual-task (VM-DT) had a significant effect on Avg-ST in the older group and on Avg. SL in young. No effects of VM dual-task were observed on the COV gait variables in the older group, however, a significant increase was observed in the COV-SL and ST in younger adults. COV-SL and COV-ST increased significantly during VM-H & V dual-task than WO for younger adults Table 3.5.3.

3.2.3 Influence of cognitive game tasks on gait variables Statistical results

(Friedman ANOVA) of effect of task conditions on the gait variables is presented in Table 3.5.2 along with the medians and Inter-quartile ranges (IQR) in Figure 3.6.3 (average values) and Figure 3.6.4 COV values). Further analysis was performed, to determine, which DT tasks were significantly different than the walk alone condition. The results, i.e. p-values for each significant pair wise comparison are presented in Table 3.5.3. Visuospatial cognitive game dual-task (VSCG-DT) had a significant effect on all average gait variables; SL, ST, SwT, and, SsT in older age group and only on the Avg-ST in younger adults. VSCG-DT had a significant effect on COV-ST, SwT, and SsT in older adults and no effect in the young group. Post hoc pairwise comparisons (Wilcoxon test) presented in Table 3.5.3 older group showed a significant decline for VSCG-DT and VSCGV-DT on all average gait variables; SL, ST, SwT, and, SsT as compared to WO. Also, the COV's of all temporal gait variables, COV-ST, SwT, and SsT for older adults were significantly greater for VSCG-G as compared to WO.

3.2.4 Dual-task effects on visuomotor task outcome measures Statistical results of the (Two-way repeated measure ANOVA) are presented in Table 3.5.4 along with the Means

and standard error of mean (SEM) in Figure 3.6.5A. Showed, that VM-DT had a significant main effect on the Total residual error (TRE) and on the Amplitude Variability. Besides, there was a statistically significant interaction for Amplitude Variability $F(1, 17) = 9.1, p < 0.01, \eta^2 = 0.32$ (η^2 is effect size 0.3 moderate). Post hoc pair wise comparison (Tukey's test) showed that VM dual-task increased the total residual error in younger adults and not for the old. Also, VM dual-task increased amplitude variability in both groups, with a greater effect in older adults.

3.2.5 Dual-task effects on cognitive game task outcome measures Statistical results (Two-way repeated measures ANOVA) are presented in Table 3.5.4 along with the Means and standard error of mean (SEM) in Figure 3.6.5B. Showed, that CG dual-task had a significant main effect on Average Response time and Success rate. Post hoc pair wise comparison (Tukey's test), showed that during walking, average movement time increased significantly in young adults ($p < 0.05$) but not for older adults. Also, Success rate declined significantly in older adults as compared to younger adults ($p < 0.05$).

Note: We have computed the dual-task cost for, both average and COV gait variables for different dual-task conditions to conduct a systematic between and within group comparisons, i.e., to evaluate differential effects of different task conditions on the gait performance. However, the primary findings of our study showed that the VM dual-task affected the gait variables in the young, but not in older adults and the VSCG dual-task had an impact on gait performance in older adults, but not in younger adults. Thus, between group comparison of different tasks would have a limited value, i.e. supporting primary results.

3.3 Discussion

The purpose of this study was to examine age effects on the DT performance during treadmill walking combined with visuospatial cognitive tasks. We assessed the interference between a visuospatial task and walking in aging, by comparing the performance between younger and older adults in both tasks. The visuomotor dual-task had a significant effect on the gait variables in younger adults but no effect in older adults. However, visuomotor performance in standing was significantly lower (2-3 times) in older age group as compared to the young. Conversely, the visuospatial cognitive game dual-task had a significant effect on the gait variables in older adults but no effect in the younger group. Success rate decreased during DT walking, but only in the older adults. Response time increased during DT walking in the younger age group, but not for the older adults. To note, the response time for the older age group was nearly twice as that of the younger group when tested in single-task, i.e. standing.

The single-task, walk alone showed that older adults walked with shorter stride, step and swing durations as compared to the younger adults. In addition, older adults exhibited a high gait variability during the walk alone condition, i.e. all COV's were twice that in the young; these findings are in agreement with [22-24]. An increased gait variability in older adults is indicative of reduced gait stability and associated with fall [3,25]. Changes in the average gait variables are related to age-related changes in pacing and/or rhythm [26].

When tested in standing (at baseline), both VM task performance measures; total residual error (3 times) and amplitude variability (twice) were substantially greater in the older group as compared to the younger group. Review of the raw data-trajectories,

revealed that the movement amplitude of the older adults during the VM tracking task was typically greater than the reference target motion amplitude, i.e. a considerable amount of overshoot at the turning points.

The VM task in the present study required continuous visual observation and foveation to determine the relative positions of 2 moving objects, (position error) and to use this visual feedback to maintain or restore their overlap by using head rotations. This also required continuous head motion. This is a closed-loop process with respect to head motion as opposed to an open loop process whereby the head is rotated in synchrony with a moving target similar to cyclic movements paced by a metronome. To note, during treadmill walking there is a considerable amount of passive head motion [16,27]. Thus, during treadmill walking both the smooth pursuit system and the Vestibular ocular reflex (VOR) would function to enable fixation on the moving visual targets and thus, feedback needed to maintain their overlap.

In a study by Jagckinski et al. 1994 [28] who examined the age effects on smooth pursuit using a tracking test similar to the present visuomotor tasks. The task was done in sitting with head stationary and the participants used a hand held joystick to move a computer cursor and to follow a moving computer target. They computed the tracking error, i.e. difference between the participants and computer reference trajectory and showed that the older adults had a significantly higher tracking error than younger adults. This is consistent with the results of the present study, which included an active head motion (baseline) and active and passive head motion (during walking). It is likely that the older adults adopted an open-loop tracking strategy that required little attentional or computational load, i.e. one that addressed the movement frequency and used the turning

points to guide or pace the head rotations, but not continuous visual attention and using visuo-spatial feedback to maintain overlap of the two objects during the entire movement cycle. For the VM task, the total residual error did not change in older adults during walking, however, younger adults showed a small but significant decline. The amplitude consistency, declined in both groups during walking as compared to standing.

Interestingly, there was a considerable increase in the gait variability (COV's) during the VM dual-task condition for younger adults, however, older adults showed no change in gait performance during the VM dual-task, with an exception of the average stride time. These findings could be explained by the fact that different tracking strategies were used by the two groups, an open-loop strategy for older adults with minimal cognitive load and the closed-loop strategy and continuous visual fixation.

Another study by Bock et al. 2014 [29] reported that executive cognitive task, which required continuous visual fixation did not have a significant decline in gait performance in older adults (aged 65 years and above), but reported an increased COV step time for the younger adults (aged 20 years and above). In addition, Malcom et al. 2014 [30] examined the effect of the visual go-no-go task (cognitive inhibition) in older (aged 60 years and above) and young adults (aged 20 years and above) and observed that there was no increase in COV step time in the older adults during DT walk. Most importantly, both these studies showed that at baseline, the percentage of correct responses [34] and response time [35] were significantly lower in older adults and did not decline further during DT- walk, which is consistent with our findings.

To note, in the present study 7 out of the 25 older participants could not perform the VM tasks during walking, i.e. they needed to hold onto the treadmill safety rails. One

likely explanation is that these 7 clients possibly had reduced smooth pursuit and or peripheral vestibular function and could not perform the tracking task while walking with large active and passive head movements.

The visuospatial cognitive game performance when tested in standing (baseline) was significantly less in the older adults as compared to the young; lower success rate and much slower response time (almost two times greater in the older adults). The visuospatial task employed in the present study was cognitively demanding, requiring timely responses (less than 1 second) to identify a moving object as the target or a distractor, to estimate its final position (diagonal trajectory) and to move the game sprite (using head rotation) in order to interact with the moving target, i.e. accuracy requirement. A number of studies have shown that specific executive functions decline with age [31-33]. For example, there's been a considerable decline in TMT-A & B, Digit and Symbol cancellation test and visual Stroop test scores. These tasks, require visuospatial attention, processing speed and cognitive inhibition. Our findings using the cognitive game task are consistent with these findings. The cognitive game task used in this study assessed "Average movement time", which in general encompasses information processing speed and other stages of motor planning. The success rate and movement variation were also measured and averaged over repeated trials (25-30 game events). A substantial decline in the success rate was observed in older adults, but no change in the average movement time or movement variation during DT walking. There was no DT effect on success rate or movement variation in the young age group, although the response time did increase during the DT walk. The present results showed that for older adults almost all average gait variables (decreased) and COV gait variables

(increased) when playing the visuospatial cognitive game task. There were no DT effects of VSCG dual task on the gait variables in younger adults.

Wolleson et al. 2016 [34] who studied the age effect of visual stroop task on walking in older adults (ages 70 years and above), reported a decrease in response accuracy during the DT walk as compared to response accuracy during single task, i.e. in a sitting. In addition, a significant decline in the average step length was observed during DT walk. No DT effects on response accuracy or the average step length were observed in younger age group. Xingda et al. 2014 [35] showed that the percentage of the correct responses for Brook's spatial memory task (short-term memory recall), decreased in the older adults during DT treadmill walking also there was a significant decrease in the average step-time and an increase in the step-time COV. No such DT effects were observed in the young.

Visuospatial processing where both the target and head is moving improves the ecological value of the test, i.e. similar to walking outdoors or crossing street. Moreover, both in response time and response accuracy (success rate) were examined and not just one or the other i.e. knowing both response time and accuracy while doing executive testing is important. Therefore, evaluating both gait and cognitive performance objectively ensures a sound methodology for the dual-task assessment. We assessed both young and old groups for Visuomotor and Cognitive game task at two different levels of difficulty during dual-task walking, which was our secondary objective. Both, horizontal and vertical visuomotor task had a similar impact on the gait performance in both age groups. As compared to the visuospatial executive cognitive game task VSCG-G (diagonal trajectory of target and distractor) where DT effects were observed on almost

all gait variables, VSCG-V (horizontal trajectory of target and distractor) had an impact only on the average temporal gait variable, but not on the COV. These executive game tasks did not have a significant impact on the gait variables in the young group. These findings are consistent with Schaefer et al. 2015 [36] who used n-back test in young (aged 20-30) and older adults (aged 65-85) who showed that different complexity may affect gait variables in a different manner in the older adults, i.e. dual-task walking at lower cognitive load had little or no effect on gait performance, but showed a significant decline, i.e. COV-ST increased substantially in the older group at higher cognitive loads (2 & 3 back task).

Different theoretical models have been proposed to explain the dual-task performance. These includes; a) Limited Resource Hypothesis, which suggests that multiple brain processes involving different brain regions are limited and this leads to a decline in dual-task performance b) The Cross-Domain Competition Model is an extension of the limited resources hypothesis, i.e. both cognitive and gait task share a common pool of resources hence, when one is challenged for example cognition, during dual tasking it leads to a decline in the performance in the other in this case gait task and vice-versa, and c) The Task Prioritization Model suggest that during dual-tasking participants may prioritize gait task when their walking balance is threatened or due to fear of fall. This is dependent on the estimation of threat to walking or standing balance and availability of information processing capacity [34]. The Cross-domain competition model, best explains the findings of the present study. The young group showed a decline in both gait and cognitive performance during the VM dual-task. This may point to the fact that dual-tasks, which compete for similar information processing resources,

i.e., which in case of the young adults was keeping track of two moving objects and walking simultaneously. Similarly, the older age group showed a substantial decline in both gait performance measures and visuospatial cognitive performance measure (Success rate) during the dual-tasks VSCG-G conditions. The younger adults neither showed any DT interference in the gait, nor in the visuospatial cognitive performance. Although, this does not support the cross domain interference, one likely explanation for this is, active young adults have a greater information processing capacity than the older adults [23].

VM dual-task showed no effect on the gait variables in the older adults. In addition, compared to a single task (standing), DT walking had no effect on the total residual error but a significant decline in amplitude consistency. Perhaps, this may be due to prioritization of gait over the visuomotor tasks. As discussed above, it is likely that the older adults adopted a strategy to limit the cognitive load by switching to an open-loop strategy, which would have limited any DT interference on gait performance. Thus, evaluating both gait and cognitive performance objectively ensures a sound methodology for dual-task assessment.

Recent trend shows that researchers are now investigating the effect of the visual tasks on DT performance, i.e. both gait and cognitive [34-36]. However, these tasks are mostly adaptations of neuropsychological tests, i.e. Stroop or Flankers that are stationary visual targets or images projected on a small computer screen and there are no interactions to catch etc. just press a button or say a word when you see the image. The present system developed by Szturm et al. 2013 [37] extends the previous DT treadmill studies to include moving visual targets visuomotor and continuous visual attention and

discrimination. This approach is beneficial as it resembles activities such as; walking in an outdoor environment. Additionally, the present study provides a comprehensive gait analysis, i.e. both average and COV for different spatiotemporal gait variables. Treadmill tends to constrain gait and may not reflect natural over ground walking patterns. The DT tests were conducted at 0.7m/s, which may seem to be slow as studies have indicated that slow gait speed might provide added stability to gait [34,38]

Several researchers alike, strongly recommend integrating standardized dual-task assessment as a part of the routine geriatric evaluation. A single DT screening, during a regular patient visit to the clinic may identify fallers and prevent a future fall, initiate early intervention and, reduce burden on the healthcare system

3.4 Conclusion

This study showed that a standardized approach allows us to differentiate between aging, dual-task effects and hypothesize possible strategies used by older adults to maintain safe walking during divided attention, i.e. prioritization. Different types of visuospatial tasks, impact the gait and cognitive performances in older adults in a different manner as compared to younger adults.

Evaluating cognitive-motor interaction under the influence of different information processing loads seems to be a potential screening method for early detection and prevention of mobility limitations and fall. Also, a comprehensive analysis of spatial and temporal features of gait over a sufficient number of consecutive steps have a greater reliability over the global domains, i.e. COV Stride time and thus, can reveal critical information about gait health in aging populations. In addition, objective evaluation of the cognitive tasks provides, the relevant information about different aspects of information processing and executive control. Dual-task gait assessment is time efficient and can be done in clinical settings as well as community centers and has a potential to be a valid non-invasive biomarker for gait and cognitive impairments.

3.5 Tables

Tables

Table 3.5.1. Demographics.

	<i>Demographics</i>	
	<i>Old</i>	<i>Young</i>
	<i>n=25</i>	<i>n=25</i>
Age	76 (3.9)	26 (6.1)
Male: Female	11:14	16:09
Gait speed	1.0 m/s	x
6MWT	602 m	x
MMSE	29 (0.44)	x
TMT-part A	45.1±3.98 s	x
TMT-part B	118.81±10.86 s	x
(x) Was not assessed in the young group		

Table 3.5.2. Summarizes results of the Friedman comparison between walk alone (WO) and visuomotor task (VM-H & VM-V) and walk alone (WO) and visuospatial cognitive tasks (VS-CG & VS-CGV) for Average and COV gait variables in the young and old group.

<i>GAIT VARIABLES</i>	<i>Visuomotor Tasks</i>		<i>Custom game</i>	
	<i>Young</i>	<i>Old</i>	<i>Young</i>	<i>Old</i>
	χ^2 , <i>p</i> -value, <i>W</i>	χ^2 , <i>p</i> -value, <i>W</i>	χ^2 , <i>p</i> -value, <i>W</i>	χ^2 , <i>p</i> -value, <i>W</i>
Avg-SL (cm)	6.077, 0.04, 0.9	0.12, 0.9	2.8, 0.2	7.4, 0.02, 0.95
Avg-ST (s)	1, 0.6	6.1, 0.04, 0.9	7, 0.02, 0.95	10, 0.006, 0.98
Avg-SwT (s)	1.6, 0.4	2.3, 0.3	1.1, 0.5	7, 0.03, 0.9
Avg-SsT (s)	1.2, 0.5	1.1, 0.5	3, 0.2	5.1, 0.056, 0.9
COV-SL	5.6, 0.05, 0.9	1.5, 0.4	2.7, 0.3	1.4, 0.5
COV-ST	6.2, 0.04, 0.9	4.6, 0.09	1.4, 0.5	11.4, 0.003, 1
COV-SwT	5.3, 0.07, 0.85	2.4, 0.4	1.6, 0.4	5, 0.05, 0.85
COV-SsT	1.6, 0.4	2.4, 0.4	4, 0.08, 0.2	10, 0.005, 1

df = 2, χ^2 Chi Square statistics, COV's are expressed in percentages (%)

*W effect size with 0.1 is weak, 0.3 is moderate and 0.5 and above is strong only presented for significant findings***

Table 3.5.3. Summarizes the results of the Wilcoxon signed rank comparison between Walk alone and Visuomotor tasks (WO, VM-H and, VM-V) and visuospatial cognitive game tasks (WO, VS-CG and, VS-CGV) for Average and COV gait variables

<i>Gait Variables</i>	<i>Visuomotor</i>	<i>Task</i>	<i>Visuospatial cognitive game task</i>	
	<i>Young</i>	<i>Old</i>	<i>Young</i>	<i>Old</i>
	<i>p-value</i>	<i>p-value</i>	<i>p-value</i>	<i>p-value</i>
	<i>VM-H/VM-V</i>	<i>VM-H/VM-V</i>	<i>VS-CG/VS-CGV</i>	<i>VS-CG/VS-CGV</i>
Avg-SL	0.04	n/s	n/s	0.001/n/s
Avg-ST	n/s	0.04/ 0.03	0.04	0.007/0.018
Avg-SwT	n/s	n/s	n/s	0.01/0.02
Avg-SsT	n/s	n/s	n/s	0.01/ 0.01
COV-SL	0.03/0.05	n/s	n/s	n/s
COV-ST	0.03/0.04	n./s	n/s	0.03/n/s
COV-SwT	0.04/0.032	n/s	n/s	0.02/n/s
COV-SsT	n/s	n/s	n/s	0.01/n/s

p<0.05 significant n/s not significant

Table 3.5.4. Summarizes the results of a Two-way ANOVA for the effect of Physical demands (Load) and Age on visuomotor and visuospatial cognitive game tasks outcome measures

<i>Outcome Measures</i>	<i>Load</i>	<i>Age</i>	<i>Load*Age</i>
<i>Visuomotor Task (VM-H)</i>	<i>F, p-value, η^2</i>	<i>F, p-value, η^2</i>	<i>F, p-value, η^2</i>
Total residual error	111.7, 0.01, 0.8	0.5, 0.4	0.1, 0.7
Amplitude Variation (%)	84, 0.01, 0.8	4.2, 0.05, 0.2	10, 0.01, 0.32
<i>Visuospatial cognitive game task (VS-CG)</i>			
Success Rate (%)	14, 0.01, 0.4	0.3, 0.6	0.2, 0.7
Average Movement time (ms)	42.5, 0.01, 0.7	0.01, 0.9	1.3, 0.3
Movement Variation (%)	0.03, 0.8, 0.002	2, 0.18, 0.08	1.13, 0.3, 0.05

F- statistics, df degree of freedom, η^2 is effect size 0.06 weak, 0.1 moderate and, 0.2 strong.

Table 3.5.5. Summarizes the results of the Mann-Whitney test for the between-group comparison for visuomotor and visuospatial cognitive game tasks on the dual task cost (DTC) for Average and COV gait variables

<i>Gait Variables</i>	<i>Visuomotor Task</i>		<i>Visuospatial cognitive game task</i>	
	<i>U, p-value, r</i>	<i>U, p-value, r</i>	<i>U, p-value, r</i>	<i>U, p-value, r</i>
	<i>VM-H</i>	<i>VM-V</i>	<i>VS-CG</i>	<i>VS-CGV</i>
Avg-SL	58, 0.01, 0.7	45, 0.01, 0.6	65, 0.01, 0.7	57, 0.01, 0.6
Avg-ST	122, 0.01, 0.5	139, 0.05, 0.3	141, 0.01, 0.4	108, 0.01, 0.5
Avg-SwT	225, 0.3	214, 0.9,	133, 0.01, 0.5	181, 0.2
Avg-SsT	220, 0.3	147, 0.08, 0.3	224, 0.3	209, 0.5
COV-SL	271, 0.9	225, 0.9	261, 0.6	232, 0.9
COV-ST	212, 0.1	209, 0.6	262, 0.7	225, 0.8
COV-SwT	248, 0.7	194, 0.4	270, 0.9	233, 0.9
COV-SsT	219, 0.2	189, 0.4	248, 0.6	168, 0.2
<i>r effect size 0.1 is weak, 0.3 is moderate and 0.5 and above is strong</i>				

3.6 Figures

3.6.1. Experimental set-up and gait analysis method

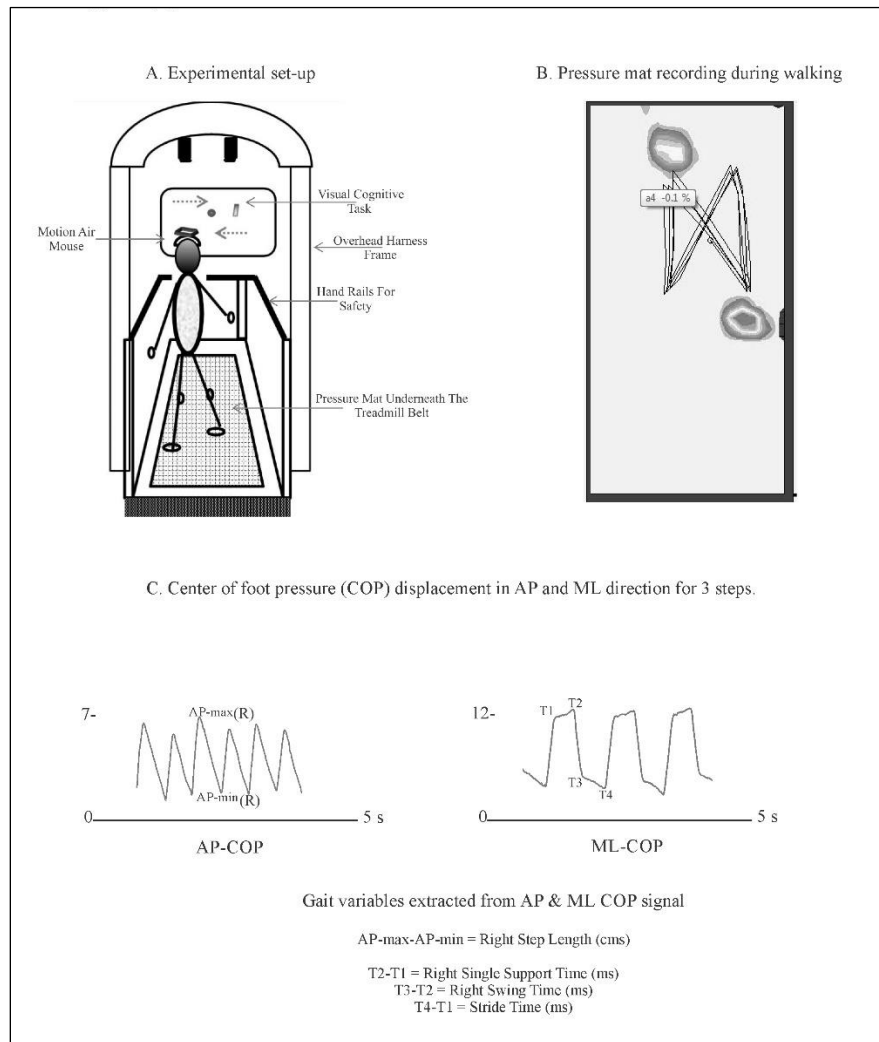


Figure 3.6.1A. Illustration of the experimental set-up

Figure 3.6.1B. Pressure mat recording during walking. Typical butterfly pattern of center of foot pressure signal. The foot contact points are recorded for both right and left feet.

Figure 3.6.1C. Center of foot (COP) pressure displacement in Antero-posterior and Mediolateral direction along with the method for extracting the gait variables from COP signal of the pressure mat.

Figure 3.6.2. Visuomotor and visuospatial game task analysis method

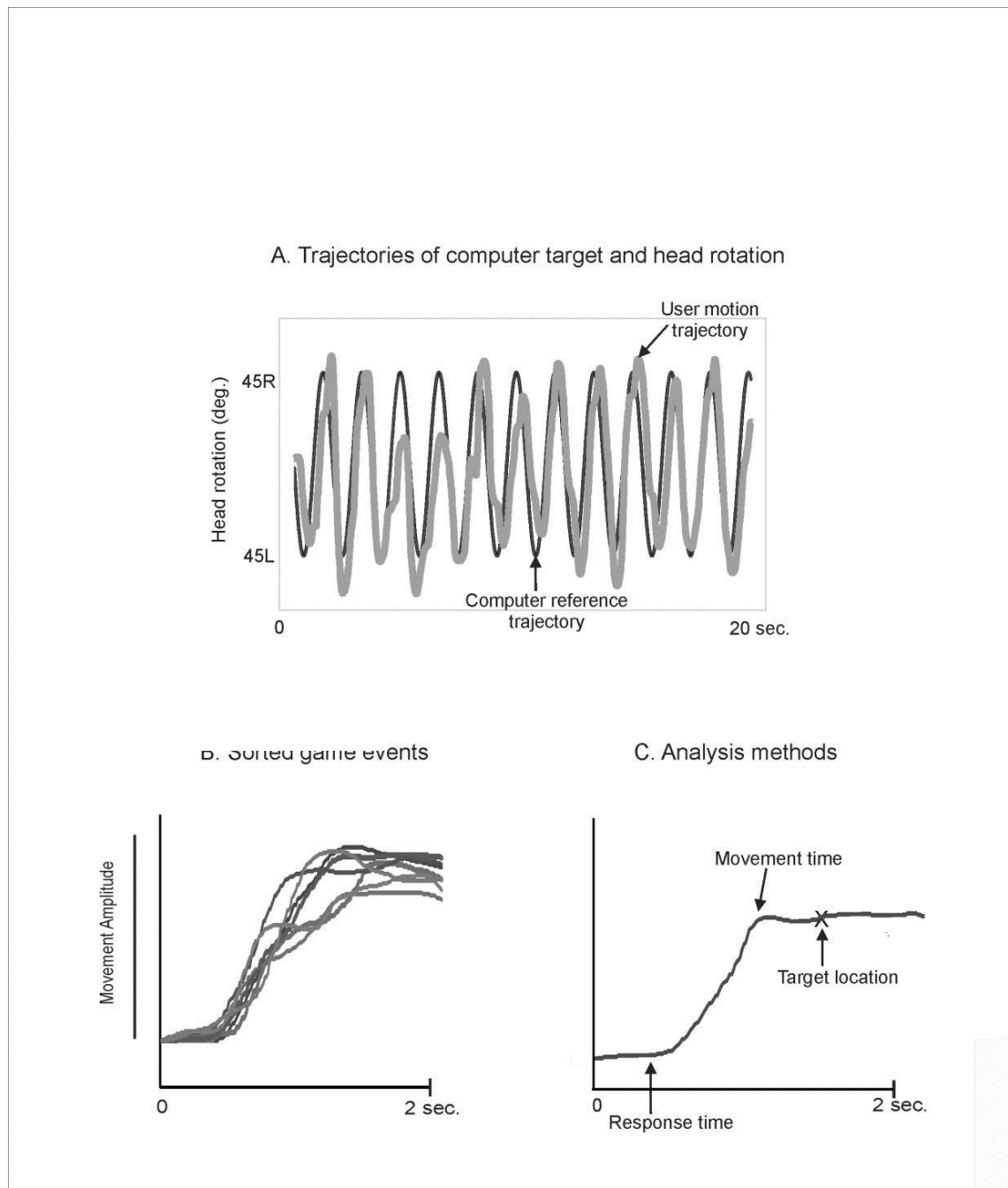
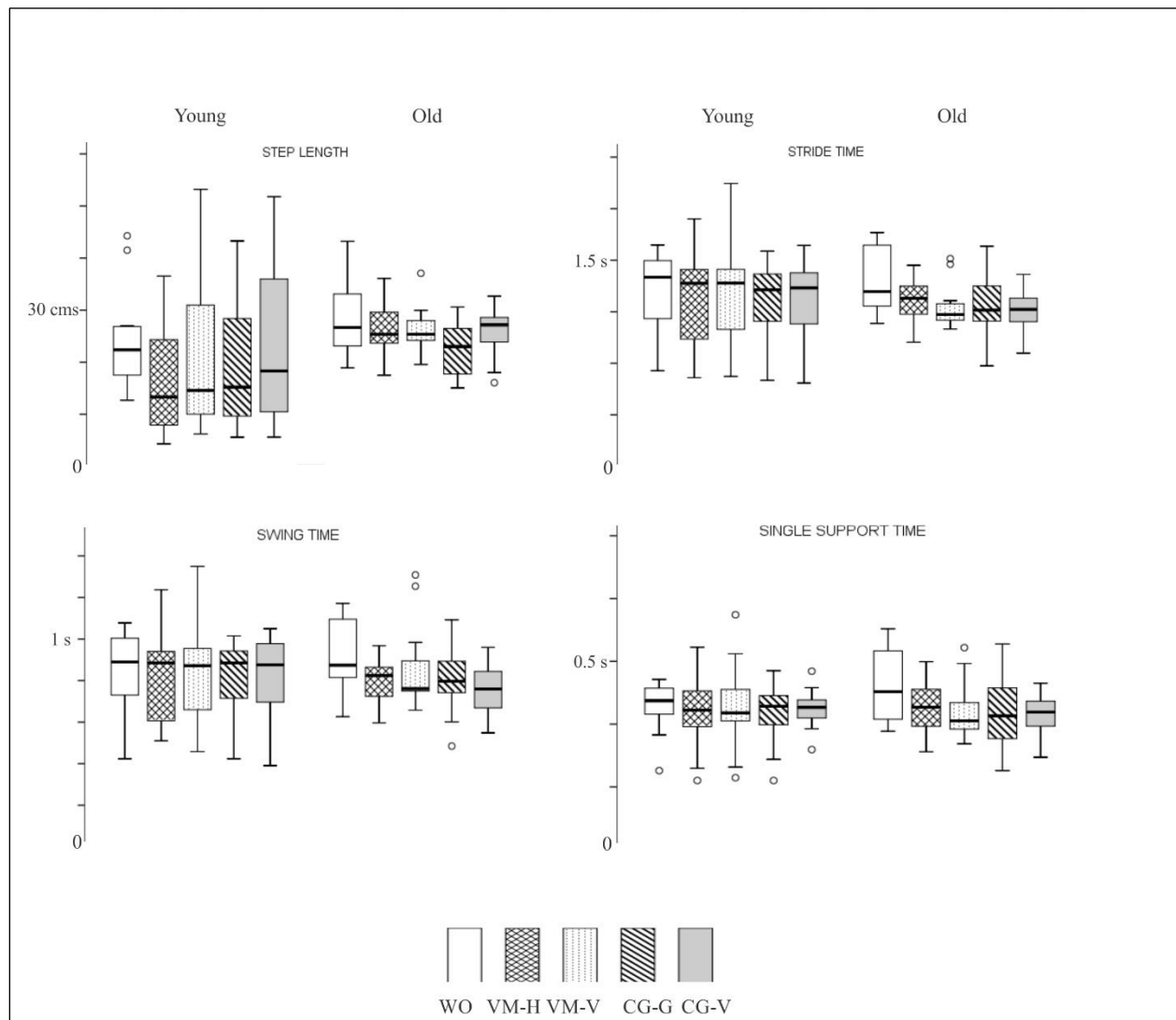


Figure3.6.2A. Shows synchronous plots of the reference and user 's head rotation for visuomotor tracking task

Figure3.6.2B. Presents overlay trajectories of individual head pointing movements for all rightward game events obtained from one game session

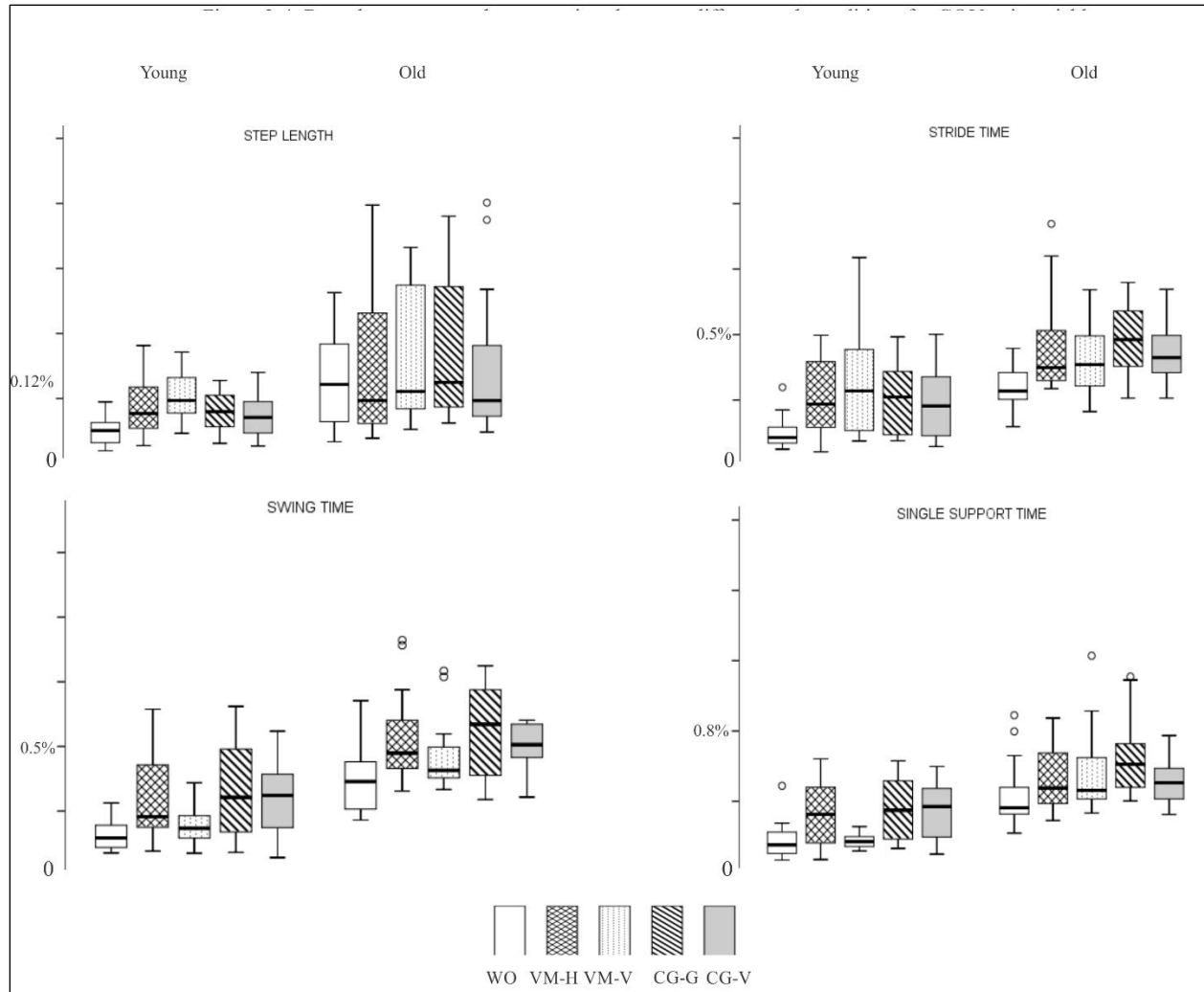
Figure3.6.2C. Shows analysis method to extract outcome measures for a single game event

Figure 3.6.3 Box plots for average gait variables for different walking conditions in young and old groups



Box-plots represents the medians and inter-quartile ranges (IQR) for the average spatiotemporal gait variables for different task conditions in young and old adults. In each graph, the panel on the left indicates group data for the young and the right panel shows the group data for the old.

3.6.4 Box plots for COV gait variables for different walking conditions in young and old groups



Box-plots represents the medians and inter-quartile ranges (IQR) for all Coefficient of variation (COV) of spatiotemporal gait variables for different task conditions in young and old adults. In each graph, the panel on the left indicates group data for the young and the right panel shows the group data for the old.

3.6.5 Bar graphs for visuomotor and visuospatial task performance measures

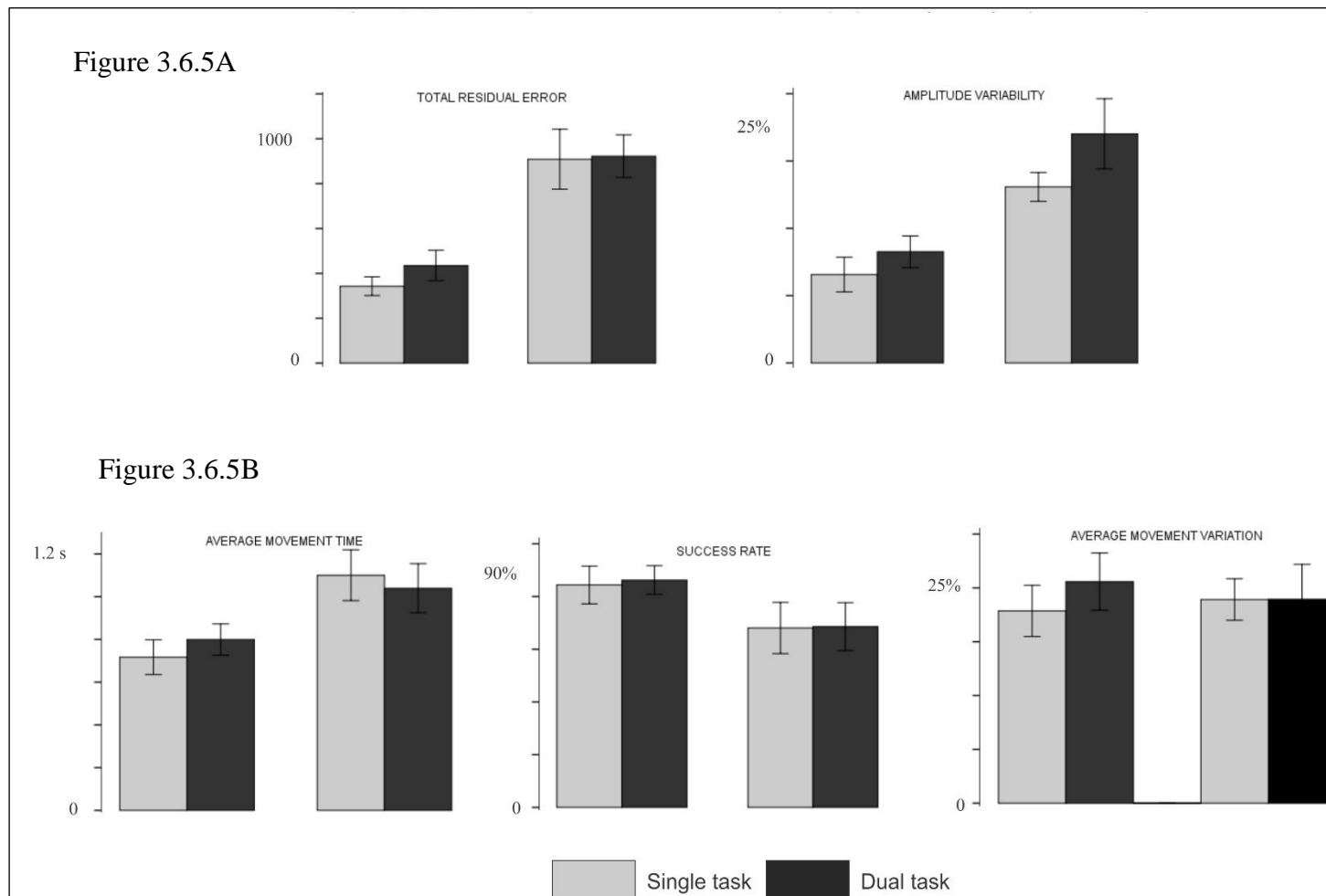


Figure3.6.5A Bar graphs represents means and standard error of mean (SEM) for visuomotor and 3.6.5B for visuospatial cognitive task game performance measure. In each graph, the panel on the left represents group data for the young and the panel on the right is group data for the old.

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Chapter 4 The Influence of Different Mental Processes on Gait: Dual-Task and Computer Games

4.1 Abstract

Background: Computer games have gained popularity to treat and prevent age-related balance impairments and cognitive decline. The purpose of this study was to examine the age effects of different visuospatial tasks, i.e. designed cognitive game and commercial computer games on dual-task gait performance.

Methods: Twenty-five older adults (ages 76 ± 3.9 years) and 25 younger adults (ages 26 ± 6.1) were assessed using computer game-based platform (CGP) where, both age-groups walked on the treadmill at 0.7 m/s for 60 seconds while playing a designed executive game task (VSCG) and 2 offline commercial computer games. Average and COV for gait variables were computed over 40 steps. Cognitive performance was evaluated only for the designed executive game task.

Results: Commercial game dual-task had a greater impact on the gait variables in younger as compared to the older adults. The VSCG dual-task had a significant impact on all gait variables in older, but only in Avg-ST in the younger adults. To note, over a third of the older adults had to hold on to treadmill safety rails during commercial game dual-tasks. VSCG dual-task walking had a significant impact on the response accuracy in older, but not for the younger adults. To note, at baseline, older adults had a lower response accuracy and slower response times as compared to the younger group.

Conclusion: This method can be used to grade and quantify the information processing loads, i.e., multiple object tracking (DT-AQ) and optokinetic stimulus (DT-JJ) of the commercial computer games, which was significantly greater for older adults than younger adults.

Key words: Dual-task, Computer games, Motor-cognitive intervention, Cognitive load

4.1.1 Background

For older adults, community ambulation is strongly associated with the preservation of skills for independent living, community participation and healthy aging [1]. Maintaining stability during walking and navigation through the environment is a complex, multi-dimensional process. Community walking (outdoor and public) requires a high level of motor control, as well as cognitive flexibility, to address threats to balance while attending to a range of environmental demands and concurrent cognitive tasks [2]. Abilities that commonly show impairment with age are those associated with performing dual-tasks in, which goal-directed behaviors have to be flexibly maintained, monitored and implemented in the face of changing memory loads, distractions, task shifting and unpredictable conditions. Several dual-task (DT) assessment studies, i.e. walking while performing mental activities such as serial subtraction, walking while talking, etc. have shown that a decline in DT performance is common in aging and mild cognitive impairment (MCI) and is associated with adverse health and falls [3-5]. Given the rapid increase in the size of the older population worldwide (World Health Organization., 2012), novel and cost effective approaches to prevent, or delay, age-related disability are societal imperatives.

Multitask training paradigms that simultaneously address both mobility and cognition benefit healthy ageing and are important to consider in rehabilitation as well as primary prevention. In this regards, the application of computer technology provides a number of promising approaches. For example, game-based platforms such as; pressure mats, Wii boards and Kinect form a basis of low-cost innovative therapies [6-8]. Another example is Virtual reality (VR) environments, viewed during treadmill walking have

recently been used to provide a more ecological and task-oriented approach to mobility training. Preliminary results suggest that mixed, augmented VR environments that incorporate both treadmill walking and cognitive tasks have potential as a rehabilitation tool. [9-11]

The use of computer games in cognitive rehabilitation programs is an emerging trend by researchers [12, 13]. Computer games have been touted for their ability to engage players in cognitive activities (e.g., decision making, learning, planning, problem solving). Commercial computer games are task specific, require an exact response to successfully play a game, i.e. are rule based; also, target executive cognitive functions, wide array to choose from i.e. (simple-to-complex) and provide lots of repetition. In addition, they are visually appealing, i.e. provides engaging environment, interactive, and easy-to-understand. Several studies have shown that the computer games are effective in training diverse executive cognitive skills [12-14]. 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 [15].

A wide range of commercial computer games are available over different gaming platforms. Based on the specific goals they are further, categorized into arcade, action, match, and strategy. These computer games engage visuospatial skills along with diverse specific executive cognitive functions, i.e., multiple object tracking, switching, updating, and inhibition skills that are necessary to deal with information in activities of daily living [16].

Szturm et al. (2013) [17] developed a standardized custom computer game-based platform (CGP), provides a means for game-based activities during walking. The purpose of this study was to explore the training value or training effect of computer games, which could be used for DT gait training interventions, i.e. whether and how different visuospatial tasks, i.e. designed computer games and commercial computer games influence or challenge dual-task walking ability in aging population. Further, draw a comparison between the designed computer games and commercial computer games. The objective of our study was to investigate the effects of different cognitive tasks, i.e. designed cognitive game and commercial computer games on gait performance in young (aged 20-35 years) as well as older (aged 70-85 years) adults. This study will test two primary hypotheses

1. Dual-task cost of the gait performance measures while performing the visuospatial executive cognitive game task will be significantly greater than the commercial game task in both age groups.
2. Increased physical demands (walking versus standing) will have a greater influence on visuospatial executive cognitive task performance measures in older adults as compared to younger adults.

A comparison between executive game task with objective outcome measures and commercial games will allow us to evaluate and grade their difficulty levels. This will eventually help in developing a graded dual-task walking intervention, which is the aim of our study. The game-based training approach may have the potential to improve clinical outcomes by making therapy more motivating, more ecological, and effective, by

blending of balance, mobility, gaze and cognitive exercises/tasks. The types and amount of cognitive stimulation, i.e. use of multiple games targeting different cognitive skills, participant's engagement during the intervention also needs to be measured, and this will help clarify the potential added benefit of activities beyond physical exercise. Using a computer-based platform, one can also objectively quantify duration and intensity of both exercise and cognitive activity. Performance can also be quantified; trend analysis can be conducted and dose-response relationships can be established.

4.1.2 Methods

Study design: Two-group experimental study.

Ethics: The Institutional Review Board at University of Manitoba approved this study HREB 2014:330. The old group data for the gait and cognitive outcomes reported herein is a subset of another study HREB 2014:293, which was conducted using a similar platform [18].

Recruitment and Participants & Material and methods are presented in Chapter 3, Szturm et al. 2013 & Szturm et al. 2016 [2,15]

4.1.3 Visuospatial cognitive tasks

Figure 4.6.1. Visuospatial executive cognitive game task

The goal was to move a paddle (the game sprite) to interact with moving game objects. For this purpose, hands-free head rotation via the motion mouse was used to move the game sprite (paddle) and catch the target objects while avoiding distractors. The software

presents moving target objects appearing at random locations on the monitor from the top end of the screen. In response to each “game event” (target appearance) the client produces a short duration ramp movement (0.5 to 1.5s) to catch the moving target for 30 game events. The settings, i.e. event duration, size of the target and the distractor were kept the same for both groups. The target was a solid orange ball and distractor was a snowflake, which changed its color at every game event. Both, the target and distractors had a diagonal trajectory.

Commercial computer games

Big fish games

In addition, to the designed cognitive game task, participants played two games downloaded from <http://www.bigfishgames.com>, these platform games selected from a collection of over 60 purchased games; we used them to target executive cognitive function, i.e. speed of processing, cognitive inhibition, working memory and visual search.

a) Aqua ball: Typical brick buster game. The game paddle is fixed at the bottom end of the screen so that it can move from left-right and right-left direction. The objective of this game task was to use a paddle to deflect the moving ball. The ball would hit the paddle levitate up and hit the bricks (seashells) and travel back to the bottom of the screen where paddle would deflect the ball again. This required continuous attention to track the

trajectory of the ball. The broken shells would release a number of objects, i.e. game points or power-up & down.

b) Jet jumper: a flight based game where one is required to navigate a jet on a narrow pathway around obstacles. The onscreen game avatar (jet) was moving forward at a constant speed, which was computer-controlled. The game background moved during navigation and jumps thus, providing a low to moderate intensity optokinetic stimulus. In addition, this game required random clicking of the handheld clicker to jump over the obstacles. Thus, the information processing load required was different for different tasks. This, along with the treadmill walking contributed towards the computational load of the dual-task. All tasks were played with head movements. On an average, all the game tasks had 20-30 random events in one minute.

Testing protocol

All the cognitive tasks, i.e. VSCG, AQ & JJ were played for 60 seconds while treadmill walking at a fixed speed of 0.7 m/s. A single-task will be performed in standing prior to DTs. The objective of the game was explained to the participants. Participants were given one practice trial in standing to get oriented to the task before the actual test. A break of 2 minutes was provided to prevent the carry over effects after each trial. The participants were not instructed to prioritize gait or the secondary cognitive task. In addition, outcomes were recorded for the custom cognitive game, i.e. success rate, average movement time and movement variation and not for the commercial games. The older group data was taken from another study, which used a similar platform [18].

4.1.4 Statistical analyses

Descriptive statistics, including means and standard deviations, were used to describe demographic variables Table 4.5.1. The normal distribution of the data was assessed using the Levene's and Shapiro-Wilks test ($n < 50$) along with the measures of Skewness and Kurtosis. Preliminary analyses of our data showed that the assumptions of normality (Mauchly's test) were severely violated for most of the gait variables for the older group, hence, non-parametric procedures were used for data analysis. Baseline between-group (young versus old) comparison for gait and cognitive performances were conducted using a Mann-Whitney test for spatiotemporal gait variables.

To test our first hypothesis, i.e. whether DT walking affect Average & COV gait variables in young and older adults, we conducted Friedman's test for both groups, young and old separately here cognitive game task (VSCG), commercial game (AQ), and Jet Jumper (JJ) was compared with Walk alone (WO, VSCG, AQ, and JJ). Post hoc pairwise comparisons were conducted to see; which tasks are significantly different from each other using the Wilcoxon signed rank test (WSRT). A Mann-Whitney test was conducted for between age group comparison. This was done by computing the Dual-task cost was computed using formula $\frac{ST-DT}{ST} \times 100$ for both average and COV gait variables.

Finally, to observe the effects of the physical demand, i.e., dual-task walking in both age groups, a Two-way repeated measure ANOVA was conducted on the cognitive game outcome measures; Success rate, Average movement time and Movement variation.

The significance level was $\alpha=0.05$. All statistical analyses were conducted using SPSS v22.0 software. [19,20]

4.2 Results

Ten out of the 25 older participants needed to hold on to the treadmill side rails for support during DT-JJ task; this was also the case for 6 out of 25 older participants in DT-AQ. The participants who held on to the treadmill rails were excluded from the analyses. Therefore, the sample size for the older group was 15 for DT-JJ and 19 for DT-AQ and 25 for VSCG game.

4.2.1 Baseline between group comparisons The group medians and Interquartile range (IQR) of gait variables for single task walk only (WO) are presented in Figure 4.6.2 (average values) and Figure 4.6.3 (COV values). Older adults showed significantly lower averages in all temporal gait variables: stride time, $z = 2.3$, $p < 0.02$, swing time, $z = 2.1$, $p < 0.03$ and single support time, $z = 2.5$, $p < 0.01$. In addition, the coefficient of variation (COV's) for all the gait variables were two times greater in the older age group: step length, $z = 3.2$, $p < 0.001$, stride time, $z = 3.3$, $p < 0.001$, swing time, $z = 3.1$, $p < 0.001$, and single support time, $z = 3.2$, $p < 0.001$. Also, for the baseline cognitive game performance measures (Figure 4.6.4), Average movement time was significantly greater, ($t_{49} = 6.2$, $p < 0.01$), and Success Rate was significantly lower, $t_{49} = 2.2$, $p < 0.04$ in older adults as compared to the younger adults. No age difference was observed for Movement variance, $p < 0.05$

4.2.2 Dual-task effects on gait variables Statistical results (Friedman's test) are presented in Table 4.5.2 along with the Medians and Interquartile ranges in Figure 4.6.2 (average gait variables) and Figure 4.6.3 (COV gait variables). Further analysis was performed (Wilcoxon pair wise comparison) to determine, which dual-task conditions were

significantly different than the walk alone (WO) condition. The results, i.e., z- statistics and p-values for each significant pair wise comparison are presented in Table 4.5.3.

Dual-task (DT) walking conditions led to a significant decline in almost all average temporal gait variables, i.e., average stride time, swing time and single support time in both older adults and the younger adults.

DT walking also led to a significant increase in the COV stride time and COV single support time in older adults. The younger adults showed a significant increase only for COV step length and not others.

Post hoc pair wise comparisons showed that compared to the single task walk alone (WO), average stride time and average swing time declined significantly in the older adults for all three DT walking conditions, i.e. VSCG, AQ and JJ. A similar trend, was observed for the younger adults, i.e. average stride time declined significantly for VSCG and AQ, but not for JJ during DT walk. Younger adults showed that relative to WO, Average swing time declined significantly only for the DT-AQ and Average single support time declined significantly for both, DT-AQ and DT-JJ.

The COV's for all temporal gait variables, i.e. COV ST, SwT and SsT, were significantly greater in older adults for VSCG dual-task than WO. Younger adults showed that the COV step length was significantly greater for both, DT-JJ and DT-AQ than WO.

Statistical results (Mann-Whitney) are presented in Table 4.5.4. Compared to the younger adults, the older adult showed a significantly higher dual-task cost for the following gait variables; average swing time and average single support time for VSCG dual-task.

4.2.3 Dual-task effects on visuospatial cognitive game task outcome measures Statistical results (Two-way repeated measures ANOVA) are presented in Table 4.5.5 along with the Means and Standard error of mean (SEM) in Figure4. Showed that the VSCG dual-task had a significant effect on Average movement time and success rate, but not on the Movement variation. Post hoc pairwise comparison (Tukey's test), showed that the average movement time increased significantly in young ($p < 0.05$) but not for the older adults. Also, the success rate, declined significantly in older adults as compared to younger adults ($p < 0.05$).

4.3 Discussion

The purpose of this study was to investigate the effect that different visuospatial tasks, i.e. designed cognitive game and commercial computer games, have on the gait variables in older as compared to younger adults. In general, compared to the commercial game tasks, visuospatial cognitive game task had a significant impact on the gait variables in the older adults. The commercial computer game dual-tasks had a substantial effect on dual-task gait performance in the younger adults. Also, no DT effects of designed cognitive game task on were seen on the gait variables in the younger adults.

Dual-task walking while playing the jet jumper game task (DT-JJ) had a significant impact on almost all average temporal gait variables; stride time, swing time and single support time in both age groups and an increase in COV step length only in the younger adults. This was an arcade flight game with moving backgrounds, i.e. optokinetic stimulation. This objective of this game task was to maintain the jet (game sprite) on a small path and to click at random intervals with the handheld clicker (mouse) to jump over the obstacles. O' Connors et al. 2015 [21] examined the effect of visuospatial task (optokinetic) on dual-task gait performance in older (70 years of age) as compared to the younger adults (25 years of age). They showed that this type of visuospatial task had a substantial increase in step length variability in the older adults but no effect in the younger group. Using a similar platform, i.e. treadmill based virtual reality (VR) Rábago et al. 2015[22] studied the effects of visuospatial task (optokinetic stimulus) on the gait variables only in the young adults. The task was to walk while viewing a projection "walking in the park", the background moved from left to right and

vice-a-versa. A significant decline in average stride time was reported, which is consistent with our findings. Although, these high-end VR systems evaluate the effect of visual stimulus i.e. optokinetic stimulus on gait and; it is an established fact that visuospatial processing of the environment plays a major role in walk safely in external environment [23]. It is unlikely that the older adults would tolerate this type of visual stimulus for intervention purpose. Most importantly, simulations i.e. walking in the park, walking through a narrow hallway or viewing an alternate pattern of doors and windows moving at different speeds, used in these studies do not target specific executive cognitive functions such as; decision making, reaction time and problem solving thus, limited training value.

Dual-task walking while playing Aqua ball game task (AQ-DT) had a significant impact on the average temporal variables; stride time, swing time and single support time, in the older adults and only on: average stride time and average swing time along with an increase in COV-Step length in the younger adults. This task required one to keep a track of multiple objects, i.e. both the target and distractors. The specific game elements were relatively small hence, required visual acuity and precision of the head movements. Pothier et al. 2014 [24] used multiple object tracking task that was projected on a screen (size 4 m²) and required one to identify discs (all with a diameter of 4.5 cms) with the same color (2 or 3), which were moving at a fixed speed between (7 to 9 distractors). Using a handheld laser, they were instructed to identify multiple targets while dual-task walking over ground 8-meters walkway (4-5 responses). As compared to the young, a significant decline in the gait speed was reported in old adults during dual-task walking also the percentage of correct responses dropped down significantly. The DT walk had a

small but significant decline in gait speed in the younger adults. Baseline assessment, i.e., during standing, revealed no significant difference in the number of correct responses between young and the older adults. This study demonstrates an explicit prioritization in older adults, i.e. when simultaneously engaged in a secondary task during a DT walk, older adults slow down. A significant decline in the gait speed is a common finding in the majority of the over ground dual-task gait studies [4, 5].

Now, the treadmill platform does not allow one to slow down or stop to think, i.e. process the information to provide a correct response, particularly when the information processing load is large [25,26]. Hence, the older adults tend to prioritize their walking over secondary cognitive task during treadmill walking. This is exactly the opposite of what has been reported in the over ground dual-task studies. This strategy, during DT treadmill walking is adopted in older adults may be due to the fear of falling.

As opposed to DT-JJ and DT-AQ, which had an effect only on average temporal gait variables in the older adults, VSCG dual-task had a significant impact on almost all average and COV gait variables in older adults. Interestingly, VSCG dual-task showed no DT effects on the gait variables in the younger group. Similar to the commercial games (JJ and AQ), this task requires visuospatial processing, inhibition and switching [16]. Cognitive outcome measures for VS-CG task; success rate and average movement time, computed over repeated trials, provides critical information regarding, information processing and the execution, i.e. motor response. Compared to younger adults, at baseline, the success rate was 15% lower in the older adults also it is important to note that the average movement time in the older group was almost twice as that in the

younger group. Also, success rate declined significantly in the older adults during DT walk, but not in the younger adults.

Although, these tests were conducted at a relatively slower walking speed (0.7 m/s), almost a third of older participants had to hold the treadmill safety rails during DT-JJ and DT-AQ. This indicates that the older adults were not able to perform these tasks i.e. these tasks seem to threaten their walking balance stability. The assessors during the tests noted that these participants frequently stumbled while playing DT-JJ and DT-AQ. This happened more frequently for DT-JJ as compared to the other dual-task conditions DT-VSCG & DT-AQ. For the jet jumper dual-task, older adults had difficulty in timing their jumps over the obstacles, i.e. either clicked too soon or failed to click at the right moment. From this, we infer that as compared to the younger, the older adults had a greater difficulty in both, anticipatory and preparatory aspects of response to the specific events of the commercial game task. Older adults, lost the game paddle on multiple occasions, i.e. mostly overshoot or undershot the game paddle while playing the DT-AQ. It seems that older adults were partially engaged in the dual-task conditions and were able to play only few game events. In addition, owing to large information processing load older adults prioritized their walking over the game tasks. Active young adults had the capacity to play these commercial games during walking, which did not seem to threaten their walking balance.

4.4 Conclusion

Commercial computer games have shown promise for cognitive-motor rehabilitation in older adults. However, these computer games lack objective outcome measures, which is a major issue. The commercial games do not allow one to record game play intensity and game play performance levels directly, so one does not know if older adults are engaged and playing the game at a similar level/intensity of the younger. Comparison with a designed computer game with multiple modes, i.e. different types of task and different complex levels with valid outcome measures will aid in evaluating the training value of these games, i.e. what types and complex levels, challenges dual-task walking balance and stability in older adults. Further, studies should be conducted to explore the training effects of diverse computer games to improve the dual-task walking ability, specific cognitive skills and community participation in aging populations. Such platforms can go into the clinical and community settings to prevent the age-associated mobility limitations and may be future falls.

4.5 Tables

Table 4.5.1. Demographics

	<i>Demographics</i>	
	<i>Old</i> <i>n=25</i>	<i>Young</i> <i>n=25</i>
Age	76 (3.9)	26 (6.1)
Male:Female	11:14	16:9
Gait speed	1.0 m/s	x
6MWT	602 m	x
MMSE	29 (0.44)	x
TMT-part A	45.1±3.98 s	x
TMT-part B	118.81±10.86 s	x
(x) Was not assessed in the young group		

Table 4.5.2. Summarizes the result of the Friedman comparison for Average and COV gait variables in young and the old group.

<i>GAIT VARIABLES</i>	<i>Young (n=25)</i>	<i>Old (n=15)</i>
	<i>χ^2, p-value, W</i>	<i>χ^2, p-value, W</i>
Avg-SL(cm)	5.2, 0.15	6.16, 0.107
Avg-ST (s)	11.4, 0.008, 0.9	9.5, 0.023, 0.6
Avg-SwT(s)	6.89, 0.077, 0.3	6.83, 0.078, 0.3
Avg-SsT (s)	12.02, 0.006, 0.9	5.4, 0.15
COV-SL	9.6, 0.02, 0.8	1.5, 0.6
COV-ST	3.6, 0.3	10, 0.016, 0.8
COV-SwT	2.42, 0.5	6.5, 0.09, 0.1
COV-SsT	6.34, 0.1	8, 0.045, 0.52

df = 2, χ^2 Chi Square statistics, $p < 0.05$ significant

COV is expressed in percentage (%)

*W is effect size 0.1 small, 0.3 medium and 0.5 large and only presented for significant findings***

Table 4.5.3. Summarizes the results of the Wilcoxon signed rank comparison between Walk alone (WO) and different cognitive tasks (CG, AQ and, JJ) for Average and COV gait variables

<i>Gait Variables</i>	<i>WO-CG</i>	<i>WO-AQ</i>	<i>WO-JJ</i>
	<i>Young/old</i>	<i>Young/old</i>	<i>Young/old</i>
	<i>z, p-value</i>	<i>z, p-value</i>	<i>z, p-value</i>
Avg-SL(cms)	n/s /2.9, 0.002	n/s	n/s
Avg-ST(s)	2.09, 0.04/2.6, 0.007	2.34, 0.018/ 2.1, 0.03	n/s /2.1, 0.04
Avg-SwT(s)	n/s/ 2.5, 0.013	2.3, 0.02/ 2.5, 0.01	1.8, 0.074/ 2.06, 0.04
Avg-SsT(s)	n/s/ 2.5, 0.008	2.1, 0.035/ n/s	2.03, 0.042/ 1.6, 0.1
COV-SL	n/s	2.2, 0.03/ n/s	2.3, 0.02/n/s
COV-ST	n/s/ 2.17, 0.03	n/s	n/s/ 1.6, 0.09
COV-SwT	n/s/ 2.34, 0.02	n/s	n/s
COV-SsT	n/s/ 2.8, 0.003	n/s	n/s
<i>z-statistics, p<0.05 significant</i>			
<i>cm centimeters, s seconds</i>			

Table 4.5.4. Summarizes the results of the Mann-Whitney test for between group comparison for dual-task cost Average and COV gait variables

<i>Average Gait Variables</i>	<i>Mann-Whitney U, Z, p-value (2-tailed)</i>
Step length	
VSCG	186, 0.26, 0.8
AQ	98, 2.7, 0.007
JJ	128, 1.67, 0.098
Stride time	
CG	148, 1.3, 0.2
AQ	177, 0.5, 0.62
JJ	172, 0.64, 0.5
Swing time	
CG	100, 2.1, 0.03
AQ	174, 0.6, 0.57
JJ	175, 0.34, 0.74
Single Support time	
CG	95, 2.2, 0.02
AQ	177, 0.5, 0.62
JJ	175, 0.34, 0.8

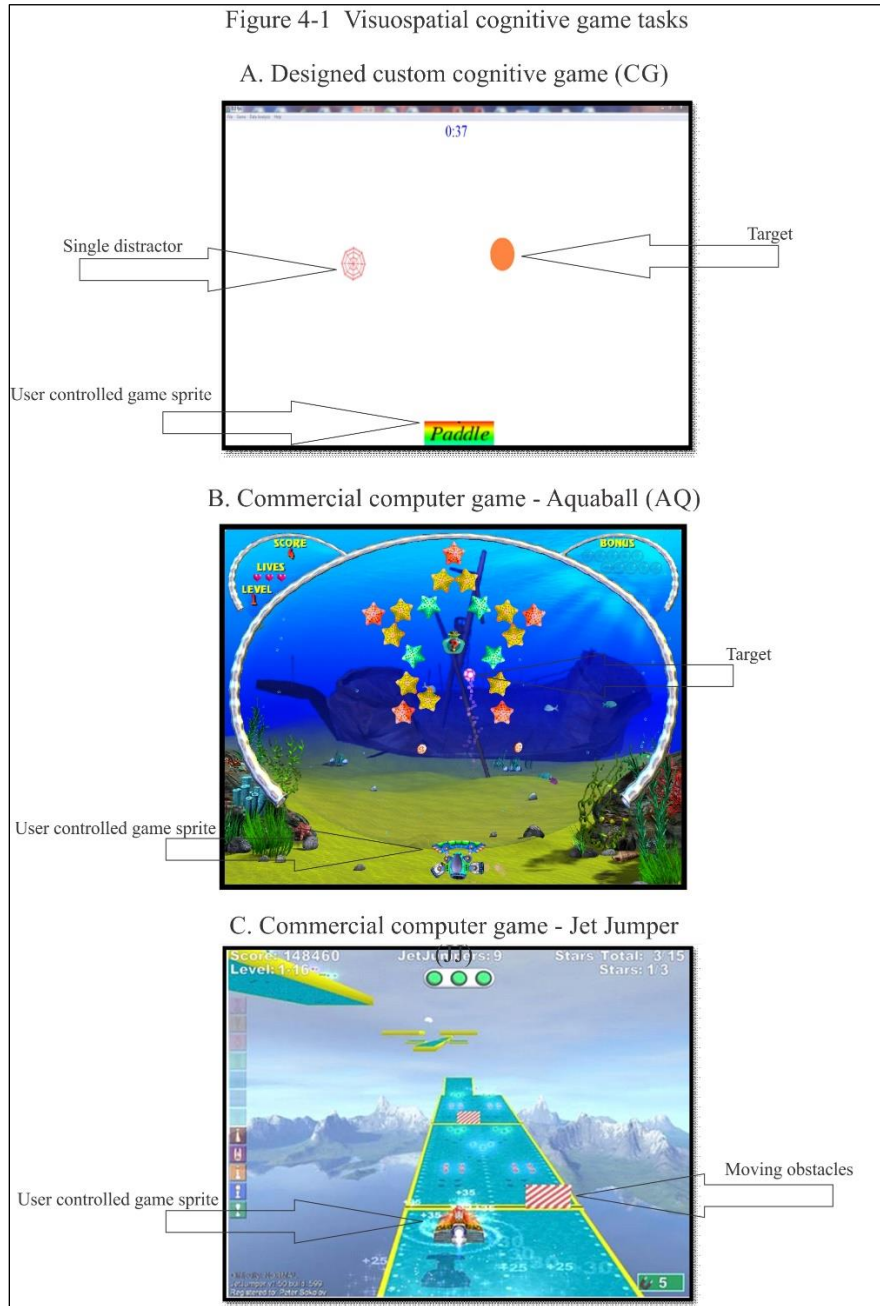
*Z-statistics, $p < 0.05$ significant, VSCG designed game task, AQ Aqua ball, JJ Jet jumper
Note: Results presented only for Average Gait variables*

Table 4.5.5. Summarizes the results of a Two-way ANOVA for the effect of Physical demands (Load) and Age on Visuospatial cognitive game tasks outcome measures

<i>Outcome Measures</i>	<i>Load</i>	<i>Age</i>	<i>Load*Age</i>
	<i>F, p-value, η^2</i>	<i>F, p-value, η^2</i>	<i>F, p-value, η^2</i>
<i>Cognitive game task (CG)</i>			
Success Rate (%)	14, 0.01, 0.4	0.3, 0.6, 0.003	0.2, 0.7, 0.003
Avg. Movement Time (s)	42.5, 0.01, 0.7	0.01, 0.9, 0.002	1.3, 0.3, 0.001
Movement Variation (%)	0.03, 0.8, 0.002	2, 0.18, 0.08	1.13, 0.3, 0.001
<i>F- statistics, df degree of freedom, η^2 is effect size 0.06 weak, 0.1 moderate and, 0.2 strong, s seconds</i>			

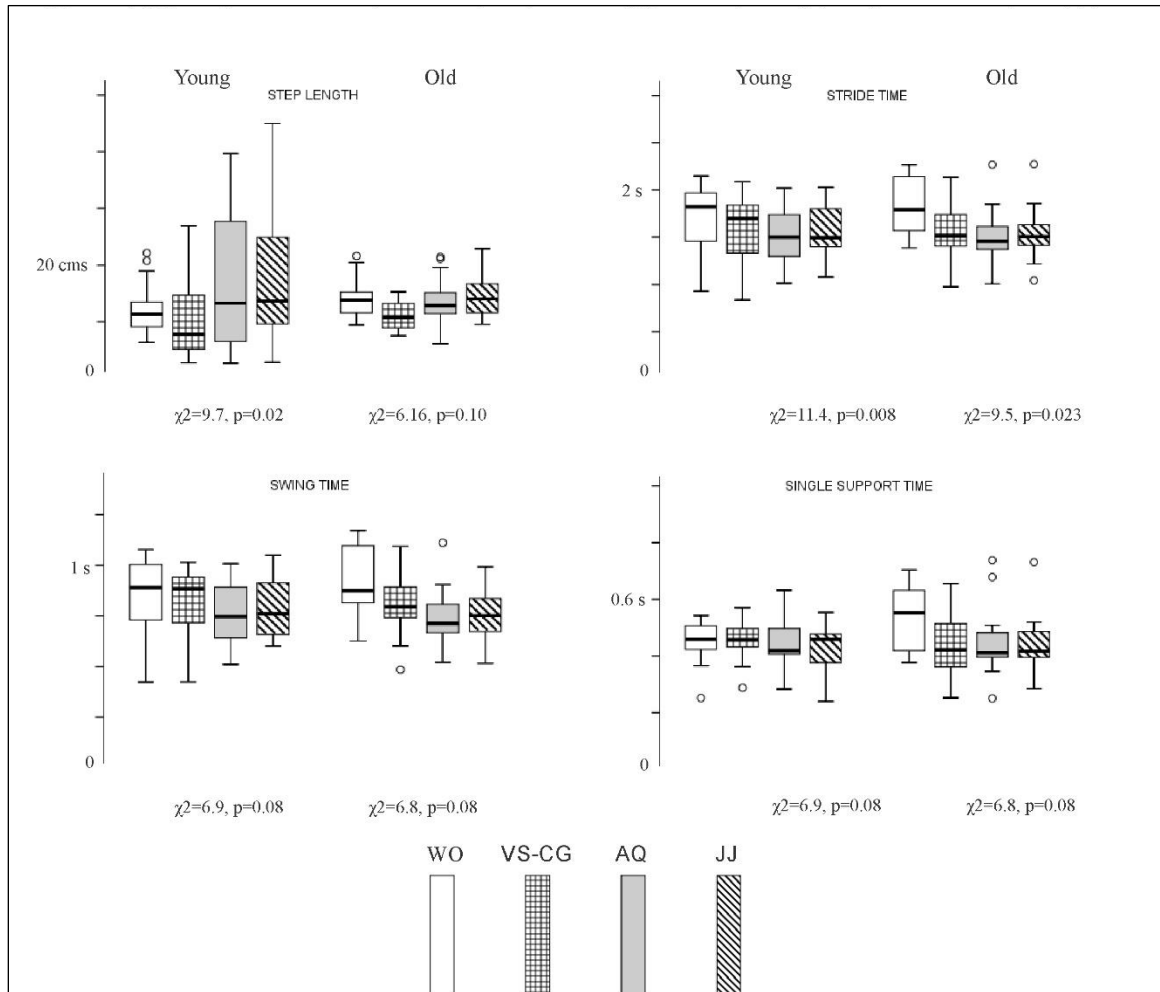
4.6 Figures

Figure 4.6.1. Screenshot of visuospatial tasks



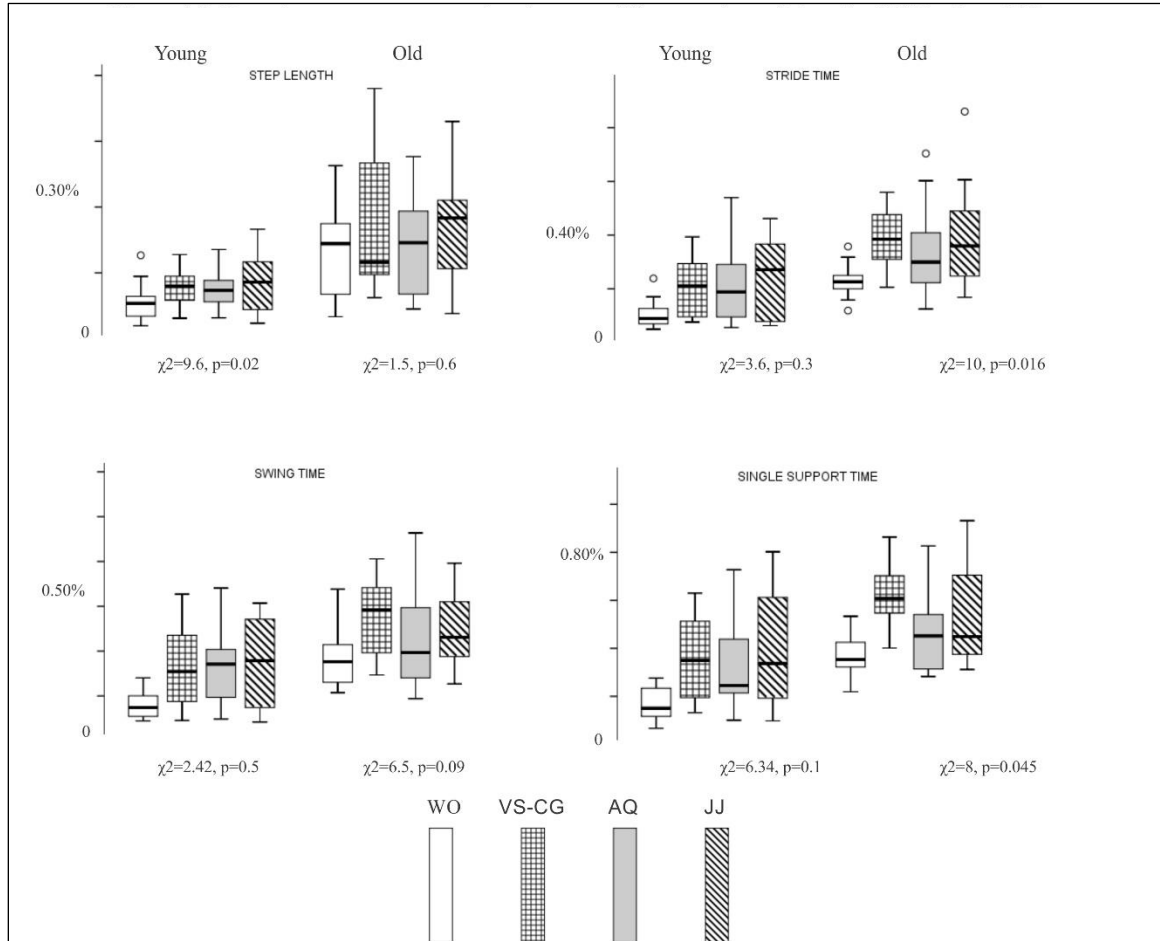
Note Please see the method section for detailed description of each task

Figure 4.6.2. Box plots for average gait variables for different walking conditions in young and old groups



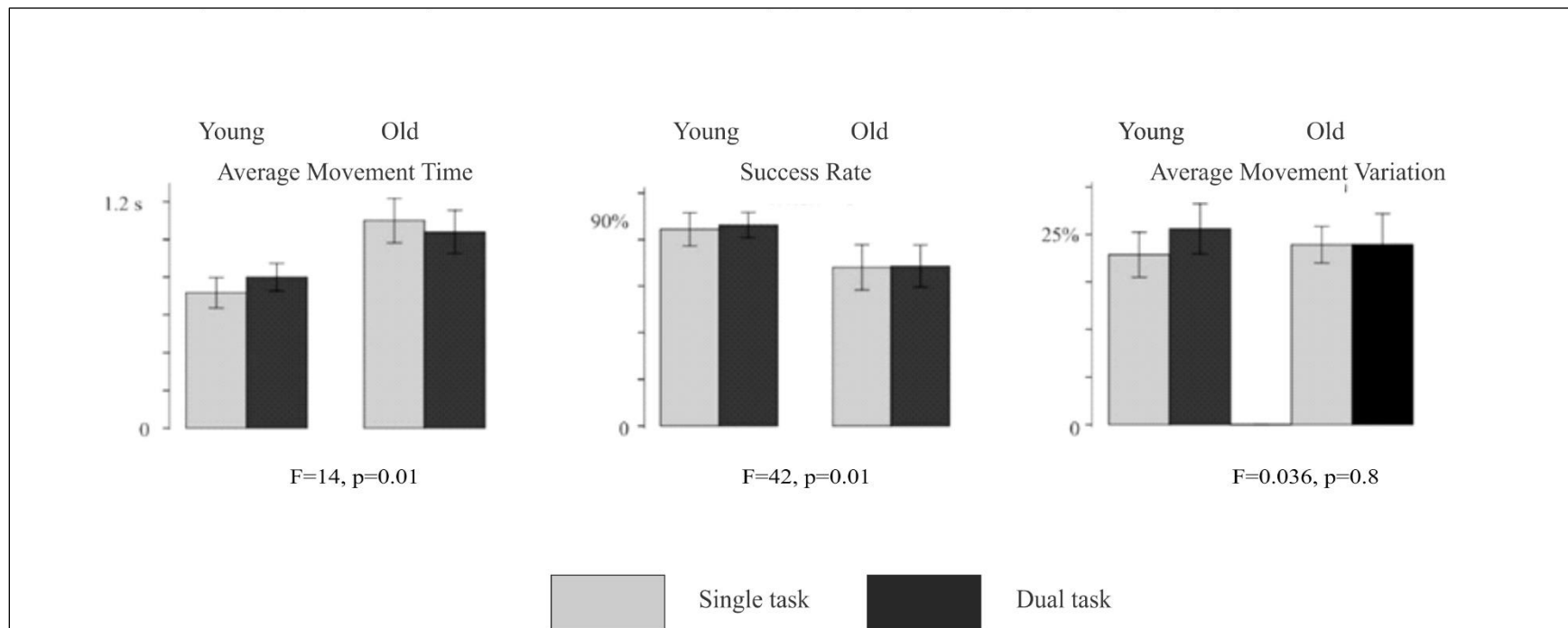
Box-plots represents medians and inter-quartile ranges (IQR) for all average spatiotemporal gait variables for different task conditions in young and older adults. In each graph, the panel on the left indicates group data for the young and the right panel shows the group data for the old.

Figure 4.6.3. Box plots for COV gait variables for different walking conditions in young and old group



Box-plots represents medians and inter-quartile ranges (IQR) for all COV's spatiotemporal gait variables for different task conditions in young and old adults. In each graph, the panel on the left indicates group data for the young and the right panel shows the group data for the old.

Figure 4.6.4 Bar graphs for visuospatial game task performance measures



Bar graphs presents group means and standard error of mean (SEM) for visuospatial cognitive task game performance measures. In each graph, the panel on the left represents group data for the young and the panel on the right is group data for the old.

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Chapter 5 Summary of findings

5.1 Dual task gait paradigm

The dual-task gait assessment is employed to assess the effect that a cognitive task has on gait variables and vice-versa, i.e. gait on cognitive task performance. This thesis was focused on addressing the specific limitations that were identified in the review of literature. The first manuscript presented in Chapter 3, evaluated the effects of two types of visuospatial tasks, i.e. having different goals, on dual-task performance (both gait and cognitive performance) in older as compared to the younger adults. The findings from this study revealed that different types of information processing load presented visually, impacts both gait and cognitive performances in the older adults in a different manner.

This study assessed both gait and cognitive performances simultaneously using a validated platform developed by Szturm et al. (2013) [72], i.e. gait speed was controlled using a treadmill platform also the type and complexity of visuospatial tasks and number of trials (20-25) for 1-minute tasks were kept constant in both age-groups. Average and COV of specific gait variables were evaluated over 40 consecutive steps for all dual-task conditions, which improved the reliability of the results for further generalization.

This study emphasized the use of visuospatial cognitive tasks, as this approach resembles walking in an outdoor environment, i.e. also the head rotations for visual search improves the ecological value of the test. Each task type, i.e. visuomotor and visuospatial executive cognitive game task were further assessed at two levels of difficulty. In older adults, assessing the same tasks at different levels of complexity may help in establishing the floor and ceiling for both cognitive and motor performance, i.e. at what level of complexity a change in gait rhythm and cognitive performance is observed. This approach in older adults may provide information about their ability to dual-task

walk in diverse, challenging environments, i.e. under the influence of visual and cognitive stimulation.

5.2 Computer games: A new frontier in dual-task intervention

Review of the relevant literature Chapter 1-1.2.5, has shown that computer gameplay while sitting over an extended period of time improves diverse executive cognitive skills, i.e. reaction time, decision making skills, etc. However, limited work has been done on how wide variety of elements in these games may have an impact on dual-task walking ability in older adults. Thus, the second manuscript presented in Chapter 4 was focused on evaluating the training value of the computer games, i.e. can these digital games be used to stress motor and cognitive systems during dual-task walking. This study evaluated whether and how different commercial games influence dual-task walking ability in older as compared to the younger adults. The present system (CGP) allowed a high-end hands free gaming experience. The findings of this study indicate that a systematic approach to computer game selection, i.e. slow paced single event or even self-paced seem to be a good starting point for training both gait and different executive functions simultaneously in the older adults. This approach can also be used for quick assessment using different types of games, i.e. match, arcade, action, adventure or strategy, which will further help us decide, what type and levels may challenge dual-task walking ability.

A common finding in both these studies was that during dual-task walking some tasks, i.e. visuospatial executive game, had a significant impact on gait variables in older adults and some do not, i.e. visuomotor task and commercial game task. Conversely,

visuomotor and commercial game task had a substantially larger impact on gait variables in the younger adults. Both the tasks, which had a limited impact on gait for older adults were the ones, which required sustained visual attention either to track two objects as seen in the VM task or track multiple objects and optokinetic stimulus as seen in the commercial computer games.

5.3 Limitations

There were a few limitations identified in this study, unequal sample size and unequal variance did necessitate non-parametric approach. This approach was more suited for our data, however, did not allow us to test the interaction effects for gait data. Data of the participants who held on to the safety rails during DT walking conditions were excluded from final analysis and this might have reduced power of our analysis. The gait speed 0.7m/s was relatively slow, especially for the younger adults as most of them engaged in recreational sports or physical training. The slow gait speed may have an added greater walking stability, which might have influenced the analysis. The treadmill platform does not reflect a natural over ground walking pattern.

5.4 Conclusion and Future Directions

In summary, the dual-task gait assessment is a valid and reliable tool/method to evaluate one's ability to deal with the moment-to-moment external stimuli while walking. It is important to evaluate both gait and cognitive performance and not just one or the other for accurate interpretation of results. Dual-task gait assessments using a standardized platform such as the one used in the present study should be integrated into geriatric assessments. The scope of such platforms must be extended beyond research

labs, i.e. into the clinical and community settings, i.e. recreational centers where community dwelling older adults come for routine exercises e.g. the Reh-fit center, and Wellness center, Winnipeg, MB, Canada. So along with physical exercises these older adults will also get some cognitive training, which is paramount in the aging communities.

Further, studies should be conducted in diverse populations for early screening in older adults who are showing an executive cognitive decline and mobility impairments. Additionally, conduct confirmatory studies to discriminate fallers from non-fallers.

Exploratory studies using advanced techniques such as; Electroencephalography (EEG) can possibly explain dual-task mechanism, i.e. how different regions of brain controlling different functions co-ordinate to process different types of visual and cognitive stimuli and its effect on walking ability in older adults.

Task-specific intervention using a wide spectrum of computer games targeting specific executive functions during dual-task treadmill has potential for a multimodal rehabilitation platform. In addition, to the DT walking abilities this approach can improve: specific executive cognitive skills, visuospatial processing, increase community participation and improve social life in older adults. Further, feasibility and efficacy of such programs should be evaluated in community settings.

Appendix 1

**RESEARCH PARTICIPANT INFORMATION AND
CONSENT FORM**

**The influence of different mental processes (cognitive loads)
on gait: Study of dual-task function.**

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You are being asked to participate in a research study. Please take your time to review this consent form and discuss any questions you may have with the study staff. You may take your time to make your decision about participating in this study and you may discuss it with your friends, family or (if applicable) your doctor before you make your decision. This consent form may contain words you do not understand. Please ask the study staff to explain any words or information you do not clearly understand.

Purpose of Study

We have developed a new rehabilitation assessment method to measure balance and walking while performing a secondary mental task. An example of this might be walking across a street while scanning for vehicles or obstacles. In order to do this safely, you need to be able to acquire and process this information accurately and quickly, but also to continue walking. **The purpose of the research study is to examine effect of dual task cost on gait parameters under different cognitive load.** This study would potentially assist in the development of an assessment tool which would detect individuals who are at higher risk for falling and for mobility problem.

Study procedures

Once you decide to participate, you will be asked a few questions about your age and health, including any present cardiac risk factors, musculo-skeletal injuries, balance or mobility problems, or other illnesses that might affect your balance and ability to walk on a treadmill.

If you take part in this study you will be asked to perform a number of computerized tracking tasks and video games first while standing and then while you are walking on a treadmill at a speed similar to your natural walking speed.

The following is a description of the computer tasks:

1. Head tracking tasks: In this task you will view moving targets on the computer monitor and be asked to match their motion by moving your head left and right and up and down rhythmically at a steady pace. For this purpose, you will be fitted with a light-weight

head band that holds a small computer mouse which senses your head rotation. Instead of using a standard hand-held computer mouse to move the computer targets, you will do so by moving your head. The picture at end of this document illustrates the set-up of the head tracking mouse. The tracking tasks would be played for 45 seconds first when you are standing and then while you is walking on a treadmill.

2. Computer games: You would be asked to play 6 different computer games. These games are targeted to challenge different mental processes, such as, reaction time, ability to avoid distractor objects, and matching objects of different colour/shapes. We have graded these games into different levels easy, moderate and difficult respectively. As above you would wear the head band and motion mouse and use head rotation to play the games. These games would be played for 60 seconds first when you are standing and then while you are walking on a treadmill.

3. You would be asked to repeat the 2 games, episodic and interactive commercial game while walking at a higher walking speed of 2.8mi/hr or 1.25 m/s

You will be given practice time for each computer game. This would be done in sitting. Also before starting the test you will be asked to walk on the treadmill for 4 minutes as a warm-up and to get accustomed to the treadmill.

You would be required to participate in 2 sessions each lasting 30minutes.

The treadmill has front and side safety rails and an overhead body support safety harness. A Physiotherapist will stand either behind or beside you during all tests.

You can stop participating at any time. However, if you decide to stop participating in the study, we encourage you to talk to the Principle Investigator. If you are interested in the results of the study you may contact the Principle Investigator at the end of the study.

Risks and Discomforts

The assessments might seem strenuous. You may feel tired and experience some dizziness after the walking assessment. Some people may feel frustrated if they feel they are unable to do all the tests well.

Benefits

You will not directly benefit from participation in this study. We hope the information learned from this study will benefit other people in the future who have balance and mobility problems.

Payment for Participation

You will receive no payment or reimbursement for any expenses related to taking part in this study.

Costs

All the procedures, which will be performed as part of the study, are provided at no cost to you

Confidentiality

Information gathered in this research study may be published or presented in public forums; however, your name and other identifying information will not be used or revealed. Despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law. The University of Manitoba Health Research Ethics Board may review records related to the study for quality assurance purposes.

No information revealing any personal information such as your name will leave the University of Manitoba.

Voluntary Participation/Withdrawal from the Study

Your decision to take part in this study is voluntary. You may refuse to participate or you may withdraw from the study at any time.

Participants who are employees of either The University of Manitoba or Health Sciences Centre or individuals associated professionally with any of the investigators can be assured that a decision not to participate will in no way affect any performance evaluation of potential participants.

Medical Care for Injury Related to the Study

You are not waiving any of your legal rights by signing this consent form or releasing the investigator from their legal and professional responsibilities.

Questions

You are free to ask any questions you may have about your treatment and your rights as a research participant. If any questions come up during or after the study or if you have a research-related injury, contact any one of the study Co-investigators: **Mayur Nankar at (204) 951 6259 or Dr. Tony Szturm (204) 787-4794**

For questions about your rights as a research participant, you may contact The University of Manitoba, Bannatyne Campus Research Ethics Board Office at (204) 789-3389. Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

Statement of Consent

I have read this consent form. I have had the opportunity to discuss this research study with Dr. Szturm, or Mayur Nankar. I have had my questions answered in language I understand. The risks and benefits have been explained to me. I believe I have not been unduly influenced by any study team member to participate in the research study by any statements or implied statements. Any relationship (such as employer, supervisor or family member) I may have with the study team has not affected my decision to participate. I understand I will be given a copy of this consent form after signing it. I understand my participation in this study is voluntary and that I may choose to withdraw at any time. I freely agree to participate in this research study.

I understand information regarding my personal identity will be kept confidential, but that confidentiality is not guaranteed. I authorize the inspection of any of my records that relate to this study by The University of Manitoba Research Ethics Board, for quality assurance purposes.

By signing this consent form, I have not waived any of the legal rights I have as a participant in a research study.

Participant signature _____ **Date** _____

Participant printed name: _____

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe the participant has understood and has knowingly given their consent.

Printed Name: _____ **Date** _____

Signature: _____

Role in the study: _____

Relationship (if any) to study team members: _____

