

**The Effect of a Novel Dual-Task Exercise Program for Balance, Mobility, Gaze, and
Cognition Skills in Community Dwelling Older Adults: A Pilot Study**

by

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A Thesis submitted to the Faculty of Graduate studies of

The University of Manitoba

in partial fulfilment of the requirement of the degree of

MASTER OF SCIENCE

College of Rehabilitation science

University of Manitoba

Winnipeg

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ABSTRACT

This thesis aimed to investigate the benefit of game-based dual-task recumbent bicycle (DT-RC) training among older adults. In addition, the thesis examined the change in cardiac fitness over an 8-week training program. Eleven healthy older adults (70-80 years old) were recruited and received an 8-week dual-task training program; combines a recumbent bicycle with interactive cognitive video games. Outcome measures were collected pre and post the intervention and included measures to assess COP for core balance, spatial-temporal gait variables, performance in visual tracking and cognitive games, neuropsychological tests and HR to workload ratio. Results showed a significant improvement in COP excursion, head tracking and success rate for cognitive games, trails making test and HR to workload ratio decreased by 44%. No significant effects were found for spatial-temporal gait variables. This study shows that the DT-RC program has beneficial effects on dual-task functions and cardiac fitness among healthy older adults.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my advisor, Dr. Tony Szturm, for his continuous guidance, feedback, and support throughout this work. I am also grateful to my internal advisor, Dr. Ruth Barclay, and external advisor, Dr. Geri Brousseau, for their expert suggestions.

My sincere thanks and appreciation is also extended to the Reh-Fit Centre who helped us in advertising our research through informing clients of this research study. Also, I am very grateful to all the volunteers who participated in this study. Without their cooperation and patience, this study would not have been possible. I would also like to thank my colleagues for their contributions to my work.

I owe my special thanks to my parents and my siblings who always motivated me to reach career heights and encouraged me to achieve my dreams and made every impossible thing possible for me.

DEDICATION

My deepest and warmest thanks go to my father, Mr. Salem Alhasani, whose love and support has kept me going. Successful completion of this work would never be possible without his constant support and encouragement. I express my heartfelt gratitude and affection to my father to whom I dedicate this thesis.

Rehab Alhasani

Winnipeg, Canada, 2015

TABLE OF CONTENTS

ABSTRACT	I
ACKNOWLEDGEMENTS	II
DEDICATION	III
TABLE OF CONTENTS	IV
LIST OF TABLES	VI
LIST OF FIGURES	VII
LIST OF APPENDICES	VIII
ABBREVIATIONS	IX
1. INTRODUCTION	1
2. LITERATURE REVIEW	4
2.1 Mobility, Cognition and Aging	4
2.1.1 Incidence of Aging Effect on Physical Abilities and Cognition.....	4
2.1.2 Mobility and Cognitive Limitations Contributing to Decline in Independence and Increased fall risk.....	5
2.2 Effect of Aging on Dual-Task Performance	9
2.3 The Effect of Dual Task Training on Physical activity and Cognitive Functions 12	
2.4 Problem Statement	17
2.5 Objectives.....	19
2.6 Hypotheses	20
2.7 Ethics Approval.....	20
3. METHODS	21
3.1 Study design	21
3.2 Sample size.....	21
3.3 Inclusion criteria.....	21
3.4 Exclusion Criteria.....	22
3.5 Recruitment	22
3.6 Randomization	22
3.7 Assessment Protocol	23
3.8 Dual-Task Recumbent Bicycle Program (DT-RC) Intervention Protocol	24
3.9 Instruments and Recording.....	25

3.10.	Outcome Measures and Data Processing.....	27
3.11.	Qualitative Study Methods	33
3.12.	Data Analysis.....	34
4.	RESULTS	36
4.1.	Process Evaluation	36
4.2.	Effect of Dual-Task Recumbent Bicycle Intervention on Standing Balance.....	36
4.3.	Effect of Dual-Task Recumbent Bicycle Intervention on Spatial-Temporal Gait Variables.....	41
4.4.	Effect of Dual-Task Recumbent Bicycle Intervention on Visual Tracking Performance	44
4.5.	Effect of Dual-Task Recumbent Bicycle Intervention on Cognitive Game Task Performances	45
4.6.	Effect of Dual-Task Recumbent Bicycle Intervention on Neuropsychological Measures.....	47
4.7.	Effect of Dual-Task Recumbent Bicycle Intervention on Cardiac Fitness	47
4.8.	Effect of Dual-Task Recumbent Bicycle Intervention on Physical Performance Tests	48
4.9.	The Feasibility of Dual-Task Recumbent Bicycle Intervention.....	49
4.9.1.	Textural description	52
5.	DISCUSSION.....	54
6.	CONCLUSION	63
	Clinical Significance.....	63
	Limitations	64
	Future Directions	65
	REFERENCES	66
	APPENDICIES	85

LIST OF TABLES

Table 01: Presents the means and standard deviations for the demographic data	36
Table 02: Results of paired t-statistics to demonstrate the effect of the intervention on RMS of AP and ML COP excursions obtained on fixed surface and sponge surface ...	38
Table 03: Results of paired t-statistics to demonstrate the effect of the intervention on Peak to Peak amplitude of AP and ML obtained on fixed surface and sponge surface ...	38
Table 04: Presents paired t-test results for COD scores performed on different physical conditions	44
Table 05: Presents results of group means, SEM and paired t-statistics for visual search, verbal fluency and TMT (A and B) before and after the intervention	47
Table 05: Presents results of group means, SEM and paired t-statistics for six minute walking test and five times sit to stand test before and after the intervention	49
Table 07: Selected significant statements informed by the participants	50

LIST OF FIGURES

Figure 01: Presents the group means and SEM for RMS of COP excursions before and after the intervention	39
Figure 02: Presents the group means and SEM for Peak to Peak values before and after the intervention	40
Figure 03: Presents the group means and SEM for averaged spatial and temporal gait variables before and after the intervention	42
Figure 04: Presents the group means and SEM for COV of spatial and temporal gait variables before and after the intervention	43
Figure 05: Presents the group means and SEM for COD scores while standing as well as walking on the treadmill before and after the intervention	44
Figure 06: Presents the group means and SEM for A. Success rate; B. Response time; C. Execution time, before and after the intervention while performing simple cognitive task during different physical loads	46
Figure 07: Presents the group means and SEM for A. Success rate; B. Response time; C. Execution time, before and after the intervention while performing moderate cognitive task during different physical loads	46
Figure 08: Presents the average for the heart rate per unit workload ratio along the dual-task recumbent bicycle intervention	48

LIST OF APPENDICES

Appendix 01: Experimental set-up. The recumbent bicycle with a computer monitor ...	91
Appendix 02: Spree Fitness Monitor	92
Appendix 03: Gyration air mouse	93
Appendix 04: Presents COP excursions in AP and ML directions under different physical conditions.....	94
Appendix 05: Testing set-up. A: Presents a participant walking on treadmill while viewing a computer monitor and using motion mouse (head rotation). B: Presents a snapshot of pressure mat recording vertical force during walking. C: Presents X–Y plots of COP displacement for 16 steps. D: Presents AP and ML COP time series data for 6 step	95
Appendix 06: Presents synchronous plots of the reference (computer) cursor motion and user movement trajectories (head rotation) for a typical tracking task	96
Appendix 07: Cognitive game analysis. A: Presents the trajectory of game paddle movements (head rotation) for one logged game file. B: Presents the overlay of individual game events segmented. C: Presents the sorted and grouped segmented game events. D: Presents the analysis methods	97

ABBREVIATIONS

AP: Anterior Posterior

ADL: Activities of Daily Living.

ANOVA: Analysis of Variance

BBS: Berg Balance Scale

BDNF: Brain-Derived Neurotropic Factor

BF: Brain Fitness

BP: Blood Pressure

COD: Coefficient of determination

COP: Center of Pressure

COV: Coefficient of Variation

CTSIB: Clinical Test of Sensory Interaction and Balance

DGT: Dynamic Gait Index

DLS: Double Limb Support

DSP: Double Support Phase

DT: Dual Task

DT-RC: Dual Task Recumbent bicycle

DT-TW: Dual Task Treadmill Walking

EO: Eyes Open

EC: Eyes Close

FSA: Force Sensory Array

HR: Heart Rate

HRR: Heart Rate Reverse

LOB: Loss of Balance

Max-HR: Maximum Heart Rate

ML: Medial lateral

MMSE: Mini Mental Status Examination

MCI: Mild Cognitive Impairment

OR: Odd Ratio

RCT: Randomized Controlled Trial

RMS: Root Mean Square

RON: Rise of Nation

RPE: Rate of Perceived Exertion

RPM: Revolution per Minute

RR: Rate Ratio

SF: Space Fortress

SPSS: Statistical Package of Social science

TMT: Trail Making Test

TRP: Treadmill Rehabilitation Platform

TUG: Time Up and GO

UFOV: Useful Field of View

VR: Virtual Reality

5xSTST: Five times sit to stand test

6MWT: Six Minutes Walking Test

1. INTRODUCTION

Aging has become one of the most significant aspects of healthcare in the 21st century. As one ages, the effects of sedentary lifestyles and chronic disabilities escalate, with the aging individual becoming substantially vulnerable to its negative outcomes. For instance, balance, mobility and cognition impairment are common with aging, leading up to physical and mental limitations. These often are the prognostic factors of future health events, including fall injuries [1-3]. Thirty percent of adults aged 65, and 50% of those over the age of 85 are more likely to suffer at least a single fall [4-6]. Not surprisingly, falls in older adults occur while walking [7]. In this regard, there is an urgent need to develop an innovative therapeutic program that results in better future health outcomes in the aging population.

It has been demonstrated that a moderate level of physical activity, especially aerobic exercises, tend to improve cardiac fitness and muscle endurance resulting in reduced risk factors for heart disorders and stroke [1, 8]. Studies have shown that increased physical activity improves muscle endurance, balance and mobility skills. Moreover, a growing body of literature provides evidence to corroborate the claim that aerobic exercise reduces the risk of developing vascular cognitive impairment and dementia among the elderly population, while resulting in decreased incidence of cognitive decline [9-12].

A number of studies have been developed that focus on cognitive training exercises to improve executive functions including processing rate, response inhibition and working memory [13, 14]. These functions are important for day to day activities,

including outdoor walking that requires balance, mobility and cognitive functions, as well as to address the threats to balancing during unpredictable environmental conditions.

In the past, mobility and cognitive function were viewed as different domains. Recently, these two systems have been studied together as our daily life requires both physical and advanced mental abilities. Dual-task training research has therefore been on a growing trend to address both mobility and cognitive functions that are critical to preventing balance, mobility and cognitive decline with age [13, 15]

The concept of the relationship between age and decline in both mobility and cognitive function is fast gaining ground. Studies have demonstrated that the use of dual-task conditions to evaluate balance-control is important for older people who are at high risk for falls [16-19]. In this respect, computer-simulated environments and interactive video games are required to promote and increase functional performance. For example, a computer game-based rehabilitation platform can be used to provide functional training while adopting a task-oriented approach in a motivating environment to encourage learning of new motor skills [20-22]. These approaches are important in order to make the intervention motivating and effective. Lately, the use of recumbent bicycles for dual-task exercise program has been observed.

This thesis is a part of a Randomized Controlled Trial (RCT) that was conducted to test the feasibility and the efficiency of game-based dual-task platform training program delivered in a community fitness centre in order to prevent adverse health events (i.e. falls). This dual-task gaming platform has been developed to be effortlessly applicable to any training program, while providing therapies for age-related decline in balance, mobility, visual tracking, cognitive executive functions and cardiac fitness.

The contribution of this thesis to the RCT was to examine the feasibility and benefit of the game-based dual-task training program as a valid platform for the community. Further, the thesis also assessed the effect of the game-based dual-task training program - combining the recumbent bicycles with interactive cognitive games - on balance, mobility, gaze, cognition and cardiac fitness skills.

2. LITERATURE REVIEW

2.1 Mobility, Cognition and Aging

2.1.1. Incidence of Aging Effect on Physical Abilities and Cognition

Shin et al. (2009) [23] examined the association of the cognitive status and the level of activities of daily living (ADL) with fall risk. 335 Korean community dwelling older adults were involved in this study (mean age: 72.87 ± 6.48 years old). They used the Mini Mental Score Examination (MMSE) to assess the cognitive status. After a one year follow up, 15% of the participants experienced falls due to the following reasons: loss of balance (8.3%), slipping (52.1%), stumbling (6.3 %) and while walking (6.3%). The majority of falls happened indoors (52%) compared to outdoors (41.7%). Also, they found that older adults who scored one unit greater on ADL scale were 1.02 times more likely to be a non-faller. Thus, fallers had a lower level of daily activity that results in a higher risk of falling.

Hong et al. (2010) [24] examined the rate of fall incidence based on age among Korean adults. 10,254 participants were involved in the study and they were divided into young adults group (age 45 to 64 years old) and older adults group (age 65 to 85 years old). They observed that the older adults group had a higher rate of fall (6.3%) compared to the other group (4.1%). Also, they observed that the number of falls requiring treatment was higher in older adults (4.3%) compared to the young adults group (1.9%).

Verghese et al. (2006) [25] found, in a large based population study, that 35% of older adults aged more than 70 years old had slow gait speed. This number increases more than 10% when the age is more than 85 years old. Also, it has been found that more

than 50% of falls occur while walking especially when it coupled with another task [26]. In this regard, it has been suggested that effective interventions should focus on dual tasking, which mean the interaction between both physical activity (i.e. walking) and cognitive functions may reduce the chance of having a fall with age [27].

2.1.2. Mobility and Cognitive Limitations Contributing to Decline in Independence and Increased fall risk

Verghese et al., (2009) [28] studied the association between gait speed and quantitative gait markers (cadence, stride length, swing, double support, stride length variability, and swing time variability) with the risk of falls. 597 participants were involved in the study (mean age: 80.5 ± 5.4 years old). Participants were asked to walk on the Gait-Rite carpet and the gait variables were calculated using 5 steps. The regression model was used to determine the rate ratio (RR) as higher values (i.e. above 1.0) indicate a greater fall risk. After 20-month of follow up, results showed that 38% of participants fell. In addition, slow gait speed was strongly associated with increasing the incidence of falls (RR= 1.069). Among the gait variables, results showed a worse performance on swing, double support phase, swing time variability and stride length variability were strongly associated with falls (RR= 1.406; RR= 1.406; RR= 1.007; RR= 1.076; respectively).

Mirelman et al. (2012) [29] studied the association between balance, mobility, cognition and dual-task walking and falls in older adults. 256 healthy, independent participants were involved in the study (mean age: 76.4 ± 4.5 years old). The Berg Balance Scale (BBS), the Dynamic Gait Index (DGI), and the Time Up and Go test (TUG) were used to evaluate balance and functional mobility. In addition, the visual Stroop test was

used to measure response inhibition. Gait speed and swing time variability were measured comparing walk alone to dual-task walking. For dual-task walks, the cognitive task was subtracting 3-series from a predefined 3-digit number. The regression model was used to determine the rate ratio (RR) as higher values (i.e. above 1.0) indicate a high level of fall risk. After 5 years of follow-up, results showed a strong association between BBS, DGI and TUG with falls (RR=0.95; RR=0.97; RR=1.08; respectively) and a moderate association between a Stroop test and falls (RR=0.85). Also, there was a moderate to strong association between a decrease in dual-task gait speed (RR=0.75) and an increase in dual-task swing time variability (RR=1.11) with falls. This finding was consistent to a similar finding reported by Herman et al., (2010); Coppin et al., (2006); Hausdorff et al., (2005); van Iersel et al., (2008); and Verghese et al., (2008) [2, 30-33].

Another major concern with an aging population is the higher prevalence of age-related impairment in cognitive functions. Community ambulation in many common daily environments requires cognitive executive processes to compensate for motor function decline and to deal with spatial functions and obstacles. Recent findings suggest that safe ambulation among older adults is more than a motor process; it also will involve executive function [34, 35]. The term executive function refers to a group of cognitive actions that include: decision making, planning for performance, speed of processing, and inhibiting task-irrelevant information [36, 37]. Also, executive function is related to visual-spatial organization [38].

Researchers have connected cognitive inhibition and processing speed abilities to competent everyday performance functioning in older adults in several areas [39, 40]. Ample evidence now exists that, as a part of the normal aging process, many individuals

experience a decline in the speed of processing at which they process information [41]. Recent research confirmed that late-life cognitive decline can be attributed to slower processing speed that, in turn affects time management and decision making abilities during daily life activities among the elderly people [42]. Several recent studies have indicated that speed of processing accounts for significant proportions of cognitive executive function decline experienced the greatest mobility loss by older adults over time [30, 32, 43-46]

McGough et al. (2011) [47] studied the association between executive functions and physical performances. 201 sedentary older adults with mild cognitive impairments (MCI) were involved in the study (mean age: 84.6 ± 5.7 years old). Gait speed and TUG were used to measure mobility and balance, respectively. In addition, Trail Making Test part B (TMT-B) and visual Stroop were used to measure processing speed and response inhibition, respectively. Results showed a strong association between TUG and TMT-B ($r^2=0.8$), and a moderate association between gait speed and both TMT-B ($r^2 = 0.7$) and Stroop test ($r^2 = 0.5$). Hence, the conclusion is that slower physical performance is associated with poorer executive functions. This finding was similar to other findings reported by Herman et al., (2010); Mirelman et al., (2012); Mielke et al., (2013); and Montero-Odasso et al., (2009) [2, 29, 48, 49].

Martin et al. (2013) [50] studied the association between executive functions and both gait speed and gait variability measures in 422 older adults (mean age: 72 ± 7 years old). Participants were asked to complete 6 walks at their self-selected speed using the Gait-Rite system. Variables collected were gait speed, step time, step length, and double support phase (DSP). In addition, speed of processing, response inhibition and visual-

spatial ability were measured using Symbol Search, visual Stroop and Rey Complex Figure Copy task, respectively. Results showed that the majority of executive functions were poorly associated with gait measures with the exception of speed of processing and response inhibition which were strongly associated with gait speed (RR= 2.42; RR= 1.57; respectively). Only speed of processing was associated with DSP (RR= 1.13). This finding was similar to other findings reported by Holtzer et al., (2007) and Watson et al., (2010) [51, 52].

Chen et al. (2012) [53] examined whether the cognitive executive functions can independently predict falls. 509 older adults were involved in the study (mean age: 72.65 ± 5.22 years old). Speed of processing and response inhibition were measured using TMT (A and B) and visual Stroop, respectively. Logistic regression was used to calculate the Odds Ratio (OR) to observe how far cognitive variables could predict falls as a higher value (≥ 1). After 3 years of follow up, they observed that speed of processing and response inhibition were strongly significant predictors of falling (OR: 1.00, OR: 1.01; respectively). This finding was consistent to similar findings reported by Springer et al., (2006); Holtzer et al., (2007); Anstey et al., (2006); and Buracchio et al., (2011) [46, 51, 54, 55].

Visual-spatial processing (in term of object related actions) is another essential factor for balance and mobility - for processing the information with respect to body and space. There is growing evidence that supports visual-spatial processing as an important factor of executive cognition function in identifying balance and gait limitations that contribute to falling in the elderly population. For example, the inability to use the vision

accurately to judge distance to a handrail while climbing stairs may result in a fall [2, 3, 15, 56-58].

Nagamatsu et al. (2009) [56] studied whether visual-spatial processing is a significant factor in predicting falls in older adults. They included an age-matched control of non-fallers and compared them with fallers (n=10 each; mean age: 69 ± 3 years old). Eriksen flanker test was used to test the visual-spatial attention. Stimuli were presented on an 18-inch colour monitor that was placed 39-inch from the standing participant. The task required the participant to keep their eyes on the fixed central cross; in addition, they needed to indicate whether the target appeared either in the right or the left visual field via button presses. Reaction time and accuracy for the visual field was recorded for both groups. Results showed that the faller group showed difficulties in response time and attention as compared to age-matched controls ($P < 0.01$). Their findings suggest that there is an indirect link between the visual-spatial processing and falls. It is may be because the absence of the motor coordination between the vision and the hands. This finding was consistent with similar findings reported by Poulain et al., (2008) [59].

2.2. Effect of Aging on Dual-Task Performance

The dual-task paradigm is defined as a procedure that requires the individual to perform two simultaneous tasks; one usually is a balance or walking task; and the other is a cognitive task. Purposeful locomotion such as walking requires the ability to adapt to both the individual goals and the everyday challenges. This would happen while carrying out a motor skill and a cognitive function at the same time, such as inhibiting the response to potential distractions to gait. For example, traffic noise during walking, reading a street sign, navigating an uneven surface.

Hausdorff et al. (2008) [60] studied the effect of dual-task walking on gait variables in healthy older adults (mean age: 76 ± 4 years old). 228 participants were involved in the study. Walk alone and dual-task walking trials were conducted. For dual-task walks, the cognitive task was subtracting 3 and 7 series from hundreds, and the Gait-Rite system was used. Average gait speed, average swing time and swing time variability were calculated. Results showed that during dual-task walking, the average gait speed and the average swing time decreased ($P<0.001$) while the swing time variability increased ($P<0.001$). This is a highly consistent finding observed by Hollman et al., (2007) and Verghese et al., (2007) [61, 62].

Theill et al. (2011) [19] studied the effect of dual-task walking on gait speed in two groups with Mild Cognitive Impairment (MCI) and a healthy age matched control (mean age: 77.2 ± 6.2 years old). 711 participants were involved in the study. Walk alone and dual-task walking trials were conducted. For dual-task walks, the cognitive tasks were counting backward from 50 by 2-series and enumerating animals. The Gait-Rite system was used to analyze average gait speed using 5 steps. Results showed that under dual-task walking, the average gait speed was significantly lower in both of the groups; however, the cognitively impaired individuals gait speed was lower under the single walking condition and under both dual-task conditions ($P<0.001$) than the cognitively healthy individual.

Plummer-D'Aamato et al. (2011) [63] performed a study comparing the effect of talking to performing executive function task (response inhibition) on gait parameters in healthy older adults (mean age: 74 ± 5.9 years old) relative to healthy younger adults (mean age: 22 ± 1.2 years old). Walk alone and dual-task walking trials were conducted.

For dual-task walks, the cognitive tasks were spontaneous speech and auditory Stroop tasks. The average gait speed, coefficient of variation (COV) of both stride time and double limb support duration (DLS) were measured using 55 steps. Results showed that under dual-task walking, there was a significant reduction in average gait speed while talking in both groups ($P < 0.05$); however, the older group experienced a higher reduction in the average gait speed ($P < 0.001$) as compared to the young group during the Stroop task. Although the increase in DLS in dual-task conditions was greater for older adults than younger adults ($P < 0.05$), stride time variability and DLS variability were significantly longer during speech than during the Stroop task in older but not younger adults ($P < 0.001$). Thus the conclusion is that the speech task is a highly challenging task that has a greater impact on gait in older adults as compared to the young adults ($P < 0.044$).

Montero-Odasso et al. (2012) [18] studied the effect of dual-task on gait variables in two groups which are MCI and healthy age-matched control group (mean age: 77.7 ± 5.9 years old). Walk alone and dual-task walking trials were conducted. For the dual-task walks, the cognitive tasks were subtracting 7 from a hundreds and animal enumeration. The Gait-Rite system was used to analyze average gait speed and COV of stride time using 5 steps. Results showed that both groups had a highly significant effect in average gait speed ($P < 0.0001$) and stride time variability ($P < 0.0008$) during dual tasking as compared to walk alone. However, average gait speed ($P < 0.0001$) and stride time variability ($P < 0.0001$) were significantly affected in the MCI group as compared to the control group. Thus the conclusion is that the MCI group had a slower walking speed

and increased stride time variability during dual-task walking as compared to the control group, regardless of the difference at single task.

From the above studies, results showed that with age the walking speed decreased and the variability of both step width and length changed under dual-tasking in older adults. These results were consistent to similar findings reported by Nordin et al., (2010); Montero-Odasso et al., (2009); Hollman et al., (2007); Davie et al., (2012); Donoghue et al., (2013); and Priest et al., (2008) [44, 49, 61, 64-66].

2.3. The Effect of Dual Task Training on Physical activity and Cognitive Functions

A number of researchers recommend that effective intervention programs to prevent falls must concentrate on training mobility and cognitive functions together. In this respect, the application of computer technology provides a number of promising approaches. For example, virtual reality (VR) environments, viewed during treadmill walking have recently been used to provide a rich environment and task-orientated approach to mobility training. Initial results suggest that VR environments when incorporated with physical activity such as walking and cognitive task have potential as a rehabilitation tool [41, 57, 67].

Prevention by training seems to be essential in order to decrease walking disorders and reduce the factors involved in falling. Exergames has been suggested to be an innovative approach to enhancing physical activity among the elderly population. With age, physical ability is gradually affected and leads to limited mobility and other health problems; however, physical activity can be an effective approach to decreasing weakness and deconditioning.

Video games have been found to be an effective means in enhancing executive cognitive functions in older adults. Studies showed that the speed of processing can be improved significantly with video games [68, 69]. Also, Cassavaugh and Kramer, (2009) [70] showed that visual-spatial processing can be significantly improved with video games. Commercial gaming systems such as Nintendo Wii require player motion and, in some cases, weight bearing to control game play [57, 71, 72]. Because of their interactive nature, this approach requires the participants to be motivated and active to win the game, which are important factors for rehabilitation [73-81].

Bieryla and Dold (2013) [82] studied the effect of Wii-fit training on standing balance control. Twelve healthy older adults were involved in the study (mean age: 81.5 ± 5.5 years old). They were randomized into experimental group and control group. The control group continued with their normal daily activities, while the experimental group completed training using Nintendo's Wii-Fit game. A pre-post test was conducted using BBS and TUG. Results showed that the experimental group showed greater improvements in balance as compared to the control group on BBS ($P= 0.037$). The TUG test didn't show any significant improvement.

Szturm et al. (2011) [1] studied the effect of the interactive balance game on improving dynamic balance control. Thirty healthy older adults age between 65-85 years old were involved in the study. They were randomized into experimental group ($n=14$) and control group ($n=13$). The control group received the typical rehabilitation program involving strengthening and balance exercises, while the experimental group received a program of dynamic balance exercises coupled with balance games. The physical Centre of Pressure (COP) position signal in anterior-posterior (AP) and medial-lateral (ML)

directions was mapped as the input to the computer games, identical to a computer mouse. Participants played the balance games while standing on a fixed surface or a compliant sponge surface. BBS, TUG, Clinical Test of Sensory Interaction and Balance (CTSIB) and spatial-temporal gait variables were assessed on a Force Sensory array (FSA) pressure mat. Results showed that both groups improved in post-treatment balance performance scores; however, the experimental group showed greater improvements in dynamic balance as compared to the control group ($p < 0.01$). TUG and the spatial-temporal gait variables didn't show any significant improvement.

Ample evidence now suggests cognitive training interventions can improve cognitive performance in healthy older adults. The most important goal of the cognitive training is the far transfer of training to broadly enhance cognitive functioning in daily life.

Strenziok et al., (2014) [83] examined the effect of 3- different cognitive video games in far transfer of training (i.e. enhancing everyday cognitive function). Forty six healthy older adults were involved (age: 70 years old) and they were randomly allocated to 6-week of cognitive training on the program Rise of Nations (RON), Space Fortress (SF) and Brain Fitness (BF) games. Pre-post training neuropsychological and information processing testing was used to assess the abilities of reasoning, problem solving, episodic and working memory. Results showed that the BF and SF games have the strongest effect, and transferred to everyday problem solving and reasoning. This finding was similar to other findings reported by Smith et al., (2009); Kueider et al., (2012); and Voss et al., (2011) [14, 72, 84].

Generally, exercise training will improve cardiac fitness and aerobic capacity outcomes that reduce the risk of many diseases such as strokes. Also, it is important to increase and maintain physical activity to improve muscle strength, endurance, balance and mobility. Studies have showed that reduced aerobic fitness has been correlated with immobility [85, 86]. Studies have also showed that in older adults, maintaining a moderate level of aerobic fitness is associated with improved cognitive performances in tasks that measure attention and executive functions [77, 87-90].

Recent clinical trials showed that aerobic exercise will reduce the chance of vascular-cognitive-impairment-progression [9, 10, 12]. In this respect, the mechanisms by which the cognitive functions are enhanced through aerobic exercise training remain to be explained.

A few human studies have tried to identify these mechanisms; for example, Erickson et al. (2011) [91] suggested that aerobic exercise may increase the Brain-Derived Neurotrophic Factor (BDNF), and that is important to preventing brain cells from dying. In addition, aerobic exercise benefits cardiac fitness as it improves blood flow and promotes gray matter brain volume, which is important for slowing the rate of cognitive impairment [9, 11, 92].

The impact of physical activity on cognition in older adults is more strongly supported by treatment studies, which show that the older adults who have completed an aerobic exercise improved their cardiac fitness; in addition, some of these studies enhanced cognitive abilities.

In a randomized clinical trial, Baker et al., (2010) [93] studied the effect of aerobic exercise on cognition in older adults (age: 70 years old). Thirty three participants

were randomized either to high intensity aerobic exercise at 75% to 85% of Heart Rate Reserve (HRR) or to a stretching control group. Pre-post-test was used to assess cardiac fitness using the graded exercise treadmill test, speed of processing using TMT-B, and response inhibition using visual Stroop. After 6 months, results showed that there was a difference between groups, as the experimental group showed a highly significant improvement in fitness compared to the control group (treadmill grade $P < 0.001$). Also, there was a difference within group effect in TMT-B and the visual Stroop, as the experimental group completed the task faster as compared to the baseline, while the control group did not ($P < 0.05$, $P < 0.04$ respectively). Thus, the conclusion is that the aerobic exercise delivers a cardiac fitness benefit; however, the results suggest that aerobic exercise would also provide a cognitive function enhancement. This finding was consistent to similar findings reported by Renaud et al., (2010); Albinet et al., (2010); Burns et al., (2008); Colcombe et al., (2004); Nagamatsu et al., (2013); Smith et al., (2010); van Uffelen et al., (2008); and Venturelli et al., (2011) [90, 94-100].

In another randomized control trial, Anderson-Hanley et al. (2012) [101] studied the effect of coupling recumbent cycling exercise with a cognitive game on enhancing executive function as compared to aerobic exercise alone. Participants ($n=38$, mean age: 75.7 ± 9.9 years old) were randomized to receive cycling exercise in addition to cognitive challenges as they observed their avatar on a screen as a virtual rider. Participants controlled their avatar by moving the bike's peddles fast and navigated to the right and left by using either computer mouse or touchpad. Others were randomized to receive cycling exercises only ($n=41$, mean age 81.6 ± 6.2 years old). They used TMT (A and B) and visual Stroop to assess speed of processing and response inhibition, respectively.

After 3 months, both groups showed a change in TMT and visual Stroop when age and education factors were controlled ($P < 0.007$, $P < 0.05$; respectively). The experimental group had a medium effect size for executive function ($d=50\%$), which was more than the control group. Also, the experimental group experienced a 23% risk reduction of clinical progression to MCI when compared to control group. Although both groups improved physically, older people who received an additional cognitive component documented a greater improvement in cognitive function (that prevents MCI progression) than those who received traditional cycling exercise alone.

2.4. Problem Statement

The decline in mobility performance and cognitive skills has become an important issue in successful aging. As people live longer, 35% to 50% of their ability in performing the daily living activities declines owing to the effects of sedentary lifestyle and illnesses [4]. A decline in balance and mobility skills with aging is considered an early indicator of future adverse health events, including falls [13]. Balance impairment and mobility limitations can occur due to the gradual decrease of the functional reserve or capacity, such as reduction in cardiac fitness, musculoskeletal fitness and neural fitness, or due to several inevitable environmental conditions [2, 3]. Another major concern in the aging population is a decline in executive cognitive functions [14, 101]. In this regard, there is an urgent need to develop new therapeutic training programs that focus on betterment of future health.

Walking is a complex task that mandates the integration of several body systems and functions [7]. For instance, independent community walking requires balance and motor skills [2, 28-32, 62], it does it requires the cognitive flexibility to navigate through

the environment while addressing the threats posed to concurrent walking and balancing movements [34, 35]. Many studies have shown that elderly adults prioritize either the walking or the cognitive component while dual-tasking [47, 53]. For instance, if they choose the cognitive task, their walking speed and spatial-temporal gait variables are affected as a consequence. Additionally, earlier studies have shown that during dual-task walking, older adults experienced higher reduction in gait speed as compared to the young adults while avoiding obstacles in walking. Also, an increased variation in both the step width and length was observed as these variable worsened in older adults compared to younger adults [44, 49, 61, 63-66].

Visual-spatial processing is an essential factor in balance and mobility. A growing number of studies are upholding the claim that visual-spatial processing is an integral aspect of executive cognition function in identifying balance and mobility limitations that contribute to falls [57, 58]. For example, walking in the community requires each individual to exercise their vision accurately and process the spatial information from the surroundings with respect to their body and space. Numerous studies have shown a certain degree of evidence that visual-spatial processing led to a significant impact on the walking function under dual-tasking in older adults [56, 59].

Correlational studies have discovered an association between diminishing cognitive executive functions and balance impairment and mobility limitations that result in falls among the elderly population [23-25, 27]. Several studies and research have corroborated the benefits of moderate levels of physical activity in improving balance and mobility skills with increasing cardiac fitness and walking ability, and in maintaining certain aspects of executive cognitive that improves independent living in older adults [1,

8, 102]. Recent studies have illustrated the use and the benefits of dual-task training programs facilitated by coupling physical activities such as aerobic exercises with action video games involving cognitive components [13]. In such a scenario, the application of computer technology is crucial in enhancing dual-task programs. Many computer games demonstrate a visual-spatial and executive cognitive component [68-70]. Also, these games can be easily managed while performing motor skills such as dynamic balance activities using a compliant sponge, walking on treadmill or cycling [1, 57, 71, 72, 82].

A mounting aging population underscores the need to identify an effective low-cost solution as well as cognitive platforms to reduce the chance of developing cognitive impairment problems. Increasing the volume of participation is an essential aspect of any intervention. Accordingly, preserving the levels of motivation and engagement are important to long term success of the training program [73-81]. A developing methodology is to combine physical activities with cognitive executive functions in order to enhance the management of balance impairments, mobility limitations, declines in cognitive function and increased falls [83].

Although promising, there exists limited published data that positively links dual-task training with enhanced physical exercises, including aerobic exercises, and interactive cognitive games with core balance and executive function skills. Thus, a more-controlled research on the effects of dual-task training for locomotion ability is needed.

2.5. Objectives

1. To examine the benefit of the game-based DT-RC training program on balance, mobility, gaze, and cognition skills.

2. To examine the trajectory of change over the 8- week DT-RC training program on cardiac fitness.
3. To examine the feasibility of the game based dual-task recumbent bicycle training program (DT-RC) by understanding study participants' lived experiences who have completed their training program.

2.6. Hypotheses

1. There is no effect on core balance and gait performance following the DT-RC training.
2. There is a positive effect on gaze performance as well as the cognitive executive functions following the DT-RC training.
3. There is a positive effect on cardiac fitness following the DT-RC training.
4. The therapeutic program is feasible as determined by the study participant.

2.7. Ethics Approval

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

3. METHODS

3.1. Study design

A mixed method design was used to analyze a subset of quantitative data followed by qualitative data from a randomized controlled trial (RCT) to explain the results of quantitative data. However, this thesis treated as a single-arm study with no comparison group.

3.2. Sample size

Eleven volunteer older adults.

3.3. Inclusion criteria

1. Age between 70 to 80 years old.
2. Living in community and being community ambulant.
3. Participants can walk 400 meters without assistive devices; however, single point cane was permitted.
4. Experiencing no more than one fall in the previous 12 months.
5. Adequate hearing and vision.
6. Speak English and provide informed consent
7. Mini Mental Score Examination (MMSE) ≥ 25 ; is the most widely used screening instrument for detection of cognitive impairment in older adults. MMSE is a 20-item instrument that used to screen five areas of cognitive functions: orientation, visual spatial abilities, attention and calculation, recall and language. MMSE is scored from 0 to 30 points. Lower scores indicate greater degrees of general

cognitive dysfunction. The primary measure is the total score of this task (max=30 points). It usually takes 5 to 10 minutes [103].

3.4. Exclusion Criteria

1. Clinical diagnosis of dementia or other severe cognitive impairment (MMSE \leq 25).
2. Self-reported history of stroke, traumatic brain injury or other neurological disorders such as Parkinson's disease and Vestibular disorders.
3. Muscular-skeletal injuries or severe orthopaedic diseases.
4. Unstable medical condition including cardio-vascular instability in the past 6 months.

3.5. Recruitment

Recruitment and screening (including diagnostics) was coordinated by staff (physicians, nurses, physiotherapists, member service and administration) at the Reh-Fit centre (Winnipeg, Canada) through informing clients of this research study and providing them with a brief overview. Research study advertisement was posted in the Reh-Fit centre with a brief description about the study. Individuals were recruited from the Reh-Fit centre where participants come for leisure, exercise and physical activities. The Reh-Fit centre has recumbent bicycles that can be easily used by the members.

3.6. Randomization

All the participants were assessed by blind assessor prior to beginning the intervention and within one week of completing the 8- week program. Following assessment, participants were randomly assigned to either the dual-task treadmill walking

program (DT-TW) or the dual-task recumbent bicycle program (DT-RC). Group assignment codes (number one for the DT-TW; number two for the DT-RC) were placed in an opaque envelope and sealed. Each individual randomly selected an envelope with the group assignment enclosed. The envelope was offered by the blind assessor after completing the assessment and the investigator opened the envelope with the participants. After that, a phone call was given by the examiner to the participants to set an appointment for the training sessions.

3.7. Assessment Protocol

The testing protocol was performed prior to beginning the intervention and within one week of completing the 8-week training program. Each participant was seen in two assessment sessions, each lasting 45 minutes. The following clinical functional tests were administered to the participants: six minute walk test (6MWT), five times sit to stand test (5xSTS), standing on fixed and compliant sponge surface with eyes open (EO) and eyes closed (EC) for 45 seconds, as per CTSIB. Participants were positioned on the treadmill, as it has side and front handrails and an overhead body support system for safety. Then, the Treadmill Rehabilitation Platform test protocol (TRP) which consists of a novel “sensored” treadmill and interactive computer-based therapeutic game applications was performed by participants by first standing on a fixed surface with progression to standing on the compliant sponge surface then walking on the treadmill at a speed of 0.9 m/s. They were asked to perform the visual tracking task, as this task requires smooth pursuit and vestibular function to coordinate eye and head motion (45 seconds). Also, two visual-spatial cognitive tasks were tested. These tasks require speed of processing, cognitive inhibition and decision making (simple and moderate; 60 seconds each). The

visual and the cognitive games were randomized into different order. Then, the neuropsychological battery (paper and pencil tests) was done while sitting which are: TMT (A and B), visual search, and verbal fluency.

3.8. Dual-Task Recumbent Bicycle Program (DT-RC) Intervention Protocol

Each participant received a 45 minute training program of cycling exercise and cognitive activities twice a week for 8-week.

1. Five minute warm up and cool down at a comfortable cycling speed to reduce the chance of musculoskeletal injuries.
2. Thirty five minutes of the DT-RC training, while viewing moving objects or words on a computer monitor and performing various tasks similar to playing brain fitness or cognitive games with rest periods as required. Participants were positioned on a recumbent bicycle 100 cm from an 80 cm computer monitor (See Appendix 01). Five to eight computer games were selected for each participant from Big Fish Games (www.bigfishgames.com). The computer games involved goal-directed cognitive activities that include a mix of precision movements to interact with game targets, search and matching tasks. A commercial motion mouse (Gyration Air Mouse, USA) was secured to a head band and used as the computer on screen cursor or sprite motion with head movement (left-right/up-down and diagonal)
3. Pedaling speed maintained a constant resistance at three, which was selected to achieve a moderate heart rate intensity of 60% of maximum. The Max-HR was calculated by using the formula $(220 - \text{age})$ [104, 105]. Rest periods were provided as required.

4. Heart rate (HR) and blood pressure (BP) were measured before and after the training.
5. Revolutions per minute (rpm), and the workload effort were recorded from the recumbent bicycle system.
6. The rate of perceived exertion (RPE) per the Borg 1-10 scale was recorded at the end of each session [106].

3.9. Instruments and Recording

1. Standing FSA pressure mapping system (Vista Medical, Ltd, Winnipeg, Canada): These are flexible thin mats (2mm thick) of variable sizes that can be placed on a fixed floor surface, or a compliant sponge surface. It has 256 piezo-resistive sensors (16 by 16) and each sensor covers an area of 2.8 cm^2 . An FSA pressure-sensing mat was used to compute the vertical center of the foot pressure (COP) position in the AP and ML directions for all tasks. Sampling frequency rate for the FSA pressure mat was 30 Hz. This application of pressure mapping systems is used in our biomedical and clinical studies of dynamic standing balance assessment and interactive game-based balance exercise regimes, for more detail see the work by Desai and his colleagues (2010) [107].
2. Treadmill (SportsArt Fitness Ltd) with a FSA pressure mapping mat: a treadmill with handrails and an overhead harness to provide safety while performing the tasks was used. A FSA pressure mapping mat embedded in thick Teflon was placed underneath the treadmill belt. It has 512 pressure sensors (16 by 32) and each sensor covers the area of 2.8 cm^2 . It was used to record vertical ground reaction forces and both spatial (step length, step width and foot location) and temporal (cycle time,

swing time, and single support time) gait variables for each step. Sampling frequency rate was 60 Hz. Treadmill walking was a good choice to be used because we can control walking speed "consistency" and provided us with 45 consecutive steps within one minute. Also, it increases safety as it provided handrails to prevent any unexpected injuries among elderly with mobility limitations, for a detailed description see the work by Szturm and his colleagues (2013) [108].

3. Recumbent bicycle (Technogym USA Corp.) with screen display that presents the frequency (speed), resistance, intensity (power in watt), duration in minutes and the distance in meters.

4. Heart Rate: The heart rate was measured using the "spree" headband (www.spreesports.com). "Spree" is an advanced technology that was integrated in the wireless Performance Optimization Device (i.e. iPhone or iPad) which fits securely in the Headband during the exercise (See Appendix 02).

5. Adapted Game controller: we identified and thoroughly tested an inexpensive, commercial, "plug-n-play" head tracking computer mouse (Gyration In-Air mouse, SMK-Link USA, cost \$75.00). Previous studies have used the approach for controlling cognitive games [109, 110] (See Appendix 03). The motion-sense mouse is small with gyroscopic and accelerometer sensors which can be used to derive angular displacement signals. The motion signals were used in a manner identical to a computer mouse to control on-screen cursor motion. We secured the motion mouse with Velcro to a headband as this method allowed head movement (left-right and/or up-down) to be used as the computer input device. With this simple method, seamless

and responsive hands-free interaction with any computer application was made possible [1, 108, 111].

6. Interactive computer game applications: A custom computer application developed by Szturm and his colleagues [1, 111] was used for testing. Also, we have used the commercial website Big Fish Games (<http://www.bigfishgames.com>).

We have tested and categorized 60 accessible, inexpensive commercial computer games for each participant from a pool of commercial games purchased from Big Fish Games. Examples of computer games used in this study were “Action Ball”, “Aquaball”, “Bejewelled”, “Birds Town”, “Brave Piglet”, “Jet Jumper”, and “Feeding Frenzy”. These computer games progressed as tolerated by each participants as follow: 1) simple cyclic target movement progressed to random moving objects; 2) slow to fast target movement; 3) large to small target size; 4) one to a number of distractors; and, 5) solid to structured background.

Generally, there are three types of game objects which are: 1) game sprite, which slaved to head tracking; 2) game target, which are objects to interact with; 3) game distractors, which must be ignored.

3.10. Outcome Measures and Data Processing

Custom built MATLAB scripts (The MathWorks, Natick, MA, version 2010) were used for extracting all the dependent variables from the data recorded.

1. Core balance performance measures

Standing balance: The test protocol consists of the following tasks: 1) eyes open (EO); 2) eyes closed (EC); 3) visual tracking task (described below); 4) visual spatial cognitive

tasks - simple and moderate - (described below). All the tasks were performed in standing position for 45 seconds on a fixed floor surface and repeated while standing on a compliant sponge surface (50.8 cm x 50.8 cm x 10.16 cm). The participants were asked to stand on treadmill with handrails and overhead support system for safety. They were positioned on a treadmill 100 cm from an 80 cm computer monitor. AP and ML COP excursions were recorded and the average Root Mean Square (RMS) of the COP excursions in both directions as well as peak to peak amplitude were computed (See Appendix 04). COP excursions were used as stability measures; an increase in the COP excursions was explained as decrease in stability [1, 58, 86, 107, 112-118].

Walking balance: Each participant was asked to walk for one minute at a fixed speed of 0.9 m/s. AP and ML COP excursions were recorded and used to compute the average and COV of 45 consecutive steps of spatial-temporal gait variables. The spatial variables were: step length (the distance between the points of contact of one foot to the same point of contact with the other foot), and step width (the side to side distance between the feet) and the variance of the foot location. The temporal variables were: single support time (the amount of time the foot is on ground), swing time (the amount of time the foot is not in contact with the ground), cycle time (the time taken by one foot from its initial contact of the cycle to the next initial contact of the next gait cycle) (See Appendix 05). These gait variables were provide a perspective on the consistency of the locomotor rhythm that represents walking stability [119, 120].

2. Visual tracking Performance Measures

A custom computer application was developed for the Dynamic Visual Acuity test. This consists of tracking a bright visual target moving horizontally (left and right) on

a computer display in a sinusoidal fashion for several cycles. This task is called the closed loop smooth pursuit tracking task with respect to head movement. In this task two cursors (sprites) of different colors appear on the monitor. One is the target cursor “reference” and the other is slaved to head rotation controlled via a head mounted motion mouse (Gyration, SMK-LINK Electronics, and USA). The target cursor moves at a predetermined frequency of 0.5 Hz with amplitude of 70% of the monitor width. The motion mouse was secured to a headband and used as the computer input device to control the motion of the second on-screen cursor via head rotation. This simple method can make seamless responsive hand-free interaction with any computer application possible. At a viewing distance of 100 cm, the task requires 80 degree of head rotation to move the cursor from the left to the right edges of the monitor. This results in horizontal head rotations of between 30 to 40 degrees, left and right of center. At a frequency of 0.5 Hz, this was equated to an average head rotation velocity of 80 °/s and a peak velocity of 120°/s. The task goal was to overlap the two cursors while moving the head to right and left. In this task, foveation is necessary to determine the amount of overlap (error) between both of the targets and the head cursors which requires smooth pursuit and vestibular function to coordinate eye and head motion.

Participants were asked to perform this task for 45 seconds while standing on a fixed and a compliant sponge surface (single task) as well as walking at 0.9m/s (dual-task). The coordinate data and time intervals of each event of the reference signal (computer reference target) and the user movement (head rotation) were used to compute gaze performance. The quality of the visual tracking (i.e. the sinusoidal movements) of the user’s head rotation with respect to the computer “reference” signal was evaluated

using Coefficient of Determination (COD). In order to obtain the sine wave function of the user signal fitted against the computer reference signal, a non-linear least squares algorithm was used to extract the variable of COD. The COD was computed depending on total and average residual difference between the user's and the computer signals. Thus, the perfect overlap of the two cursors results in an excellent gaze performance. COD is computed values between 0 and 1; higher value (i.e. close to 1) means better performance. The first two cycles of the tracking tasks was excluded in order to allow the user some time to obtain the moving target and begin tracking (See Appendix 06).

3. Cognitive game Performance Measures

This is a modified version of the Useful Field of View test (UFOV) which is validated and has been used to examine both visual-spatial processing coupled with eye-head coordination, and to examine the ability to select relevant information and ignore irrelevant information (cognitive inhibition) [108, 111]. The test games were classified as simple and moderate. For the simple test game (target-plus-distractor), the participant need to move the game sprite (paddle) to catch bright circles (targets) that fall vertically from top to bottom, while avoiding other distracting objects of different shapes and colors. For the moderate test game (target-plus-diagonal-distractor), the participants need to do the same as the simple test game, but in this one the targets and distractions fall diagonally. The objects would appear at user defined fixed intervals (two seconds) and at random locations on the monitor. The games (simple and moderate) would take about 60 seconds while the participant is standing on a fixed or sponge surfaces and during treadmill walking at 0.9 m/s. This was generate a logged game file recording (80 Hz), the signals linked with player performance with respect to game events: 1) time index and

coordinates of each game object; 2) position coordinates of the game paddle in respect to head rotation.

Features of the test game events provide a basis for objective quantification of cognitive functions, averaged over left (upward trajectories), and right (downward trajectories) game movements of medium amplitude, which include the following variables: 1) game success rate (percentage of targets that caught by participant); 2) average motor response time (the time from appearance of the target to start of the paddle movement); 3) average movement excursion time (the time from beginning of the movement to the final location). The overlay trajectory of the game paddle movement (head rotation) of the individual head pointing movements for each game event was obtained for duration of 60 seconds. Each game event was two seconds in length resulting in recording a total of 30 game events. The overlay of individual game events was segmented based on the time of the target appearing and the movement of the paddle hitting the ball. In other word, the time zero is the onset of the target appearing on the top of the screen (event onset), and end of event is time when the target is either hit by the paddle or when it disappears (See Appendix 07).

4. Neuropsychological tests

We used the Standardized Neuropsychological tests including the following:
TMT (part A and B): This is a valid, reliable well-established timed test that measures basic visual attention and scanning (Trail A) and mental flexibility/set shifting (Trail B). It has been used widely in clinical evaluations for the assessment of deficits in cognitive function [2, 29, 47, 49, 121]. It was administered in two parts which are: 1) TMT form A, the subject is required to link in ascending order a series of 25 numbers (1–2–3 ...)

arranged randomly on a page as quickly as possible. The required time to complete the test is 90 seconds; 2) TMT from B is a more demanding task as it requires the subject to switch between a set of numbers (1–13) and a set of letters (A–L), again linking in ascending order (1–A–2–B ...). The required time to complete the test is 3 minutes. The amount of time (seconds) required to complete the task and the number of errors was recorded.

Verbal fluency: This is a timed test of verbal fluency including: 1) category fluency (Animal) in which participants provide as many animal names as possible in a duration of 60 seconds; 2) letter fluency in which participants provide as many words starting with a predefined letter (F-A-S) as they could within the duration of 60 second each . The total number of correct responses was recorded [121, 122].

Visual search test: This is a valid, reliable and well-established timed and selective attention test that measures speed of processing and cognition inhibition in which the participants have to scan the visual environment for a particular object (target) among other objects (distractors) within 60 seconds. The number of correct items crossed out, using a pencil, on a piece of paper was recorded [123-125].

5. Cardiac fitness

Exercise frequency (rpm), workload effort measured as power in Watts and duration (time in minutes) was recorded from the recumbent bicycle recording system for each exercise interval. Pedaling speed at a consistent resistance at three was gradually increased to achieve a moderate heart rate intensity of 60% of maximum. A heart rate (HR) monitor was used to record the HR every 3 minutes during each session, and then

the HR per unit workload was calculated during the dual-task cycling exercises to track the change trajectory of the cardiac fitness over the 8-week training program.

6. Physical performance tests

Walking capacity/endurance: was measured using the 6MWT. Participants were asked to walk on the track at Reh-Fit Center for six minutes and the distance was recorded [112].

In addition, heart rate and blood pressure were measured before and after the test.

5xSTS Test: the test was used to assess the functional lower limb strength, balance and fall risk. Participants were asked to stand up and sit down five times on chair (height: 0.46 m.) with both arms folded over the chest and time was recorded to assess the ability to complete the test [123].

3.11. Qualitative Study Methods

To understand the study participants' lived experiences with their respective programs, 30-minute individual interviews with open-ended questionnaires were conducted after the 8-week DT-RC training program. Participants who experienced the DT-RC program met individually with the examiner and the blind assessor. The examiner asked the questions and the blind assessor recorded their responses by taking notes. The 'essence' of lived experiences of the participants with their respective interventions was captured by asking two broad questions: 1) what have you experienced in terms of the intervention? 2) What context or situations influenced your experiences with the interventions? In addition, specific probes aimed to obtain participants' perceptions related to a few topics, such as, 1) content and delivery of the exercise programs; 2)

intensity of the exercise, 3) difficulty of the exercise, and 4) recommendations or modifications for improving the exercise programs.

3.12. Data Analysis

The quantitative data were analyzed using Statistical Package for Social Science (SPSS) software for windows, version 22.0 (SPSS Inc. Chicago, IL, USA). Mean and standard deviation were calculated to address the demographic data. Mean and standard error mean (SEM) were calculated to address the normally distributed continuous variables.

A Paired t-test was used to determine the effect of the DT-RC training program on the following: 1) RMS of COP excursions and peak to peak amplitude; 2) average and COV of the spatial-temporal gait variables, which represent the quality of performance of locomotor stability; 3) COD. Measures for the visual tracking performance; 4) success rate, response time and execution time for cognitive game task performance; 5) the number of correct response for visual search and verbal fluency; 6) the time recorded for TMT (A and B); and 7) the HR/workload for the cardiac fitness.

Significance was set at $P \leq 0.05$ (two-tailed). Bonferroni corrections for multiple comparisons were used.

For the randomized controlled trial, we will test the difference between the experimental (DT-TW) and the control (DT-RC) groups on continuous and normally distributed outcome measures using repeated measure analysis of variance (ANOVA). Evaluation time point (pre-treatment versus post-treatment) will be the within group repeated factor, and the treatment (DT-TW versus DT-RC) will be the between group factor.

The supportive qualitative data were analyzed by the investigator using a content analysis approach to identify the importance of the participants experienced in term of the intervention and the context or situation influenced their experiences with the DT-RC training program. Content analysis is a tool to determine the presence of certain words with the use of exemplar quotes to support the use of certain words [126]. Each interview transcript was reviewed by the examiner and reported as textural description including brief explanation of the individual responses. The responses from participants were simultaneously coded into themes.

4. RESULTS

Eleven participants aged between 70-80 years old were recruited. All participants were living in the community and attending the Reh-Fit centre (Winnipeg, Canada) for exercise. The average gait speed was 1.8 m/s, and the average distance walked in six minutes was 617 metres. Average of perceived exertion that indicates the participants rating of exercise intensity was moderate, as defined by the Borg (10-point scale)

Table 01: Presents the means and standard deviations for the demographic data

Baseline Characteristics	Mean(SD)
Age (years)	76.1 (3.9)
Gender ratio (M:F)	5:6
MMSE	29 (0.44)
Speed (m/s)	1.8(0.6)
Distance	617(99)
5xSTST (second)	10(0.8)
Borg scale	3

M: male; F: female; MMSE: mini mental status examination; 5xSTST: five times sit to stand test

4.1. Process Evaluation

All the 11 participants performed the baseline assessment and completed the dual-task recumbent bicycle intervention and the post assessment. The attendance was 100% of training sessions. Retention rate for follow up at the 8-week was 100%. Also, no adverse events were reported.

4.2. Effect of Dual-Task Recumbent Bicycle Intervention on Standing Balance

Figures 01 and 02: Present the group means and SEM for RMS and Peak to Peak before and after the intervention. As illustrated in this figures, it can be seen that there was a 40% increase in COP excursions while standing on sponge surface as compared to fixed surface. Tables 02 and 03: Present results of paired t-test performed to demonstrate

the effects of the DT-RC intervention on standing balance performance while standing on fixed and sponge surfaces.

As presented in Table 02, the results of paired t-test revealed that there was a significant decrease in AP and ML COP excursions from pre to post intervention when tested on sponge surface under dual-task conditions (head tracking task). However, there was no significant effect of the intervention on COP excursion with eyes open sponge. To note, many participants loss of balance (LOB) from pre to post intervention during eyes closed sponge condition. In this regard, we did not analyze the magnitude for COP excursions for this condition because the sample size was small. However, we observed that the number of participants who LOB decreased from pre to post intervention; 8 versus 3, respectively.

There was no significant effect of the intervention on COP excursion when tested on fixed surface. However, there was one exception, a significant decrease in ML COP excursions during dual task condition (head tracking) on fixed surface.

As Presented in Table 03, the results of paired t-test revealed no significant effect of the intervention on ML peak to peak when tested on fixed surface or sponge surface. However, there was one exception, a significant decrease in AP peak to peak from pre to post intervention when tested on fixed surface under dual-task condition (moderate cognitive game tasks).

Table 02: Results of paired t-statistics to demonstrate the effect of the intervention on RMS of AP and ML COP excursions obtained on fixed surface and sponge surface.

RMS of COP Excursions (ML)	Fixed surface P-value (t-statistics, df)	Sponge surface P-value (t-statistics, df)
Eyes open (CTSIB)	NS	NS
Eyes closed (CTSIB)	NS	-
Visual tracking	0.002(2.735, 10)	0.008(3.428, 10)
Simple Cognitive	NS	NS
Moderate Cognitive	NS	NS
RMS of COP Excursions (AP)	Fixed surface P-value (t-statistics, df)	Sponge surface P-value (t-statistics, df)
Eyes open (CTSIB)	NS	NS
Eyes closed (CTSIB)	NS	-
Visual tracking	NS	0.004(3.851, 10)
Simple Cognitive	NS	NS
Moderate Cognitive	NS	NS

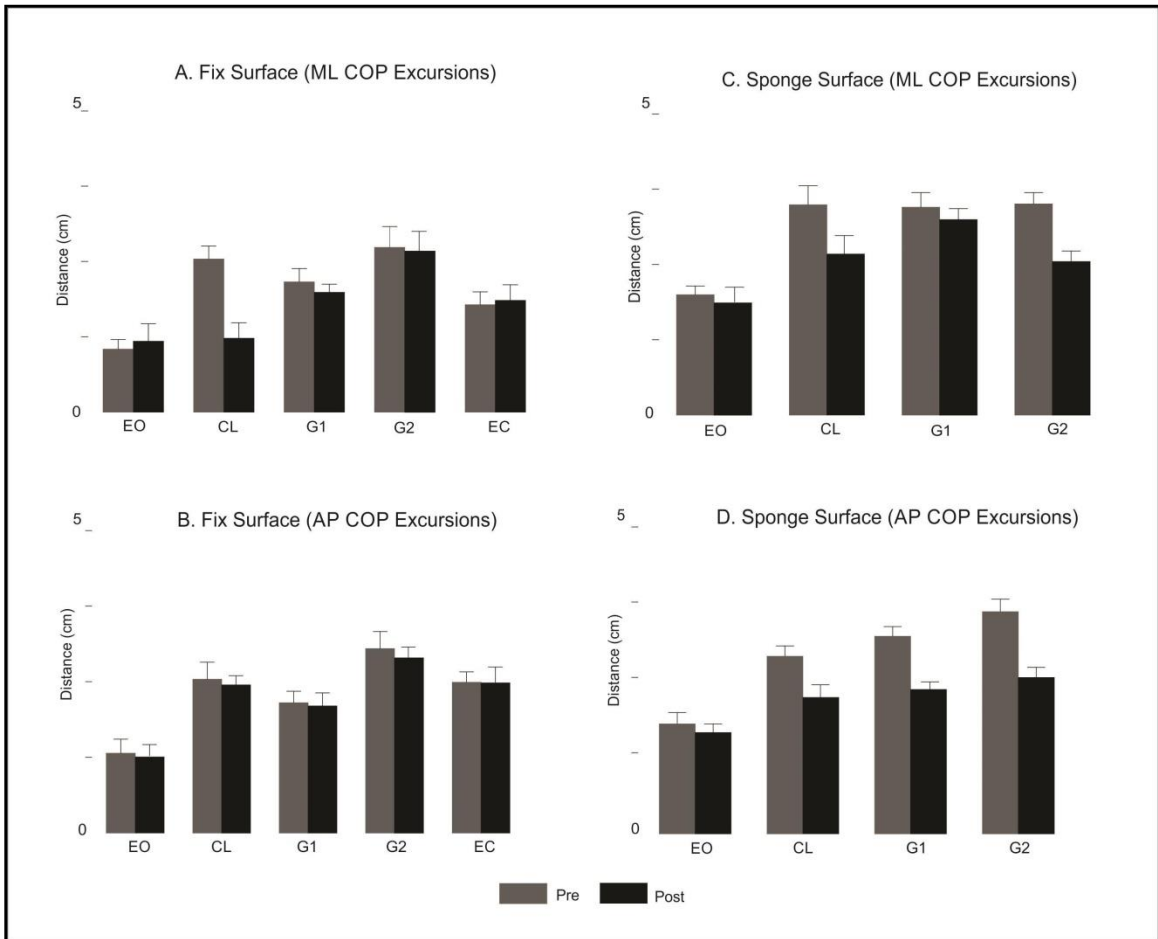
RMS: root mean square; COP: centre of pressure; ML: medial-lateral; AP: anterior-posterior; df: degree of freedom; Significant: $p < 0.05$ (Bonferroni adjusted $P \leq 0.01$); NS: Not Significant

Table 03: Results of paired t-statistics to demonstrate the effect of the intervention on Peak to Peak amplitude of AP and ML obtained on fixed surface and sponge surface.

Peak to Peak of COP Excursions (ML)	Fixed surface P-value (t-statistics, df)	Sponge surface P-value (t-statistics, df)
Eyes open (CTSIB)	NS	NS
Eyes closed (CTSIB)	NS	-
Visual tracking	NS	NS
Simple Cognitive	NS	NS
Moderate Cognitive	NS	NS
Peak to Peak of COP Excursions (AP)	Fixed surface P-value (t-statistics, df)	Sponge surface P-value (t-statistics, df)
Eyes open (CTSIB)	NS	NS
Eyes closed (CTSIB)	NS	-
Visual tracking	NS	NS
Simple Cognitive	NS	NS
Moderate Cognitive	0.002(4.290,10)	NS

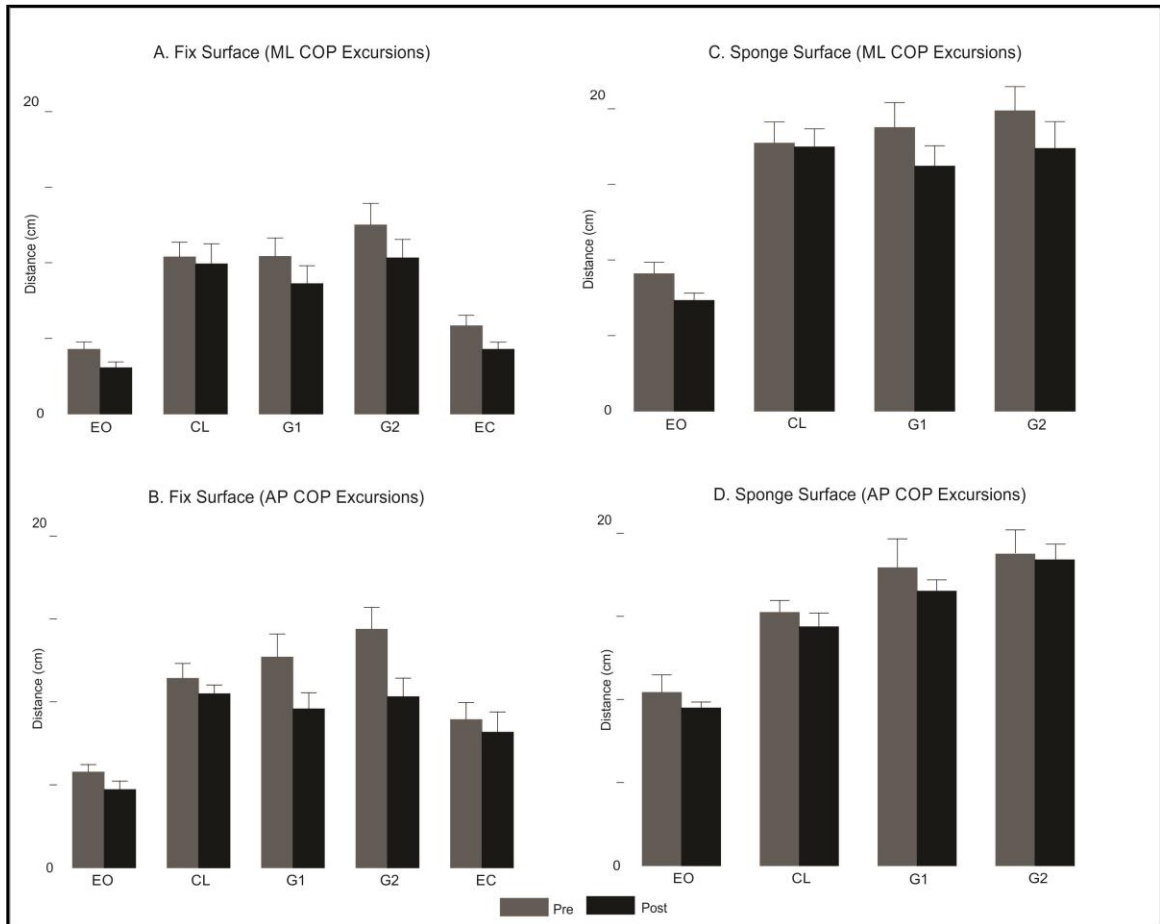
COP: centre of pressure; ML: medial-lateral; AP: anterior-posterior; df: degree of freedom; Significant: $p < 0.05$ (Bonferroni adjusted $P \leq 0.01$); NS: Not Significant

Figure 01: Presents the group means and SEM for RMS of COP excursions before and after the intervention: (A and B) Fixed surface ML and AP; (C and D) Sponge surface ML and AP



COP: centre of pressure; ML: medial-lateral; AP: anterior-posterior; EO: eyes open; CL: close loop; G1: simple game; G2: moderate game; EC: eyes closed

Figure 02: Presents the group means and SEM for Peak to Peak values before and after the intervention: (A and B) Fixed surface ML and AP; (C and D) Sponge surface ML and AP

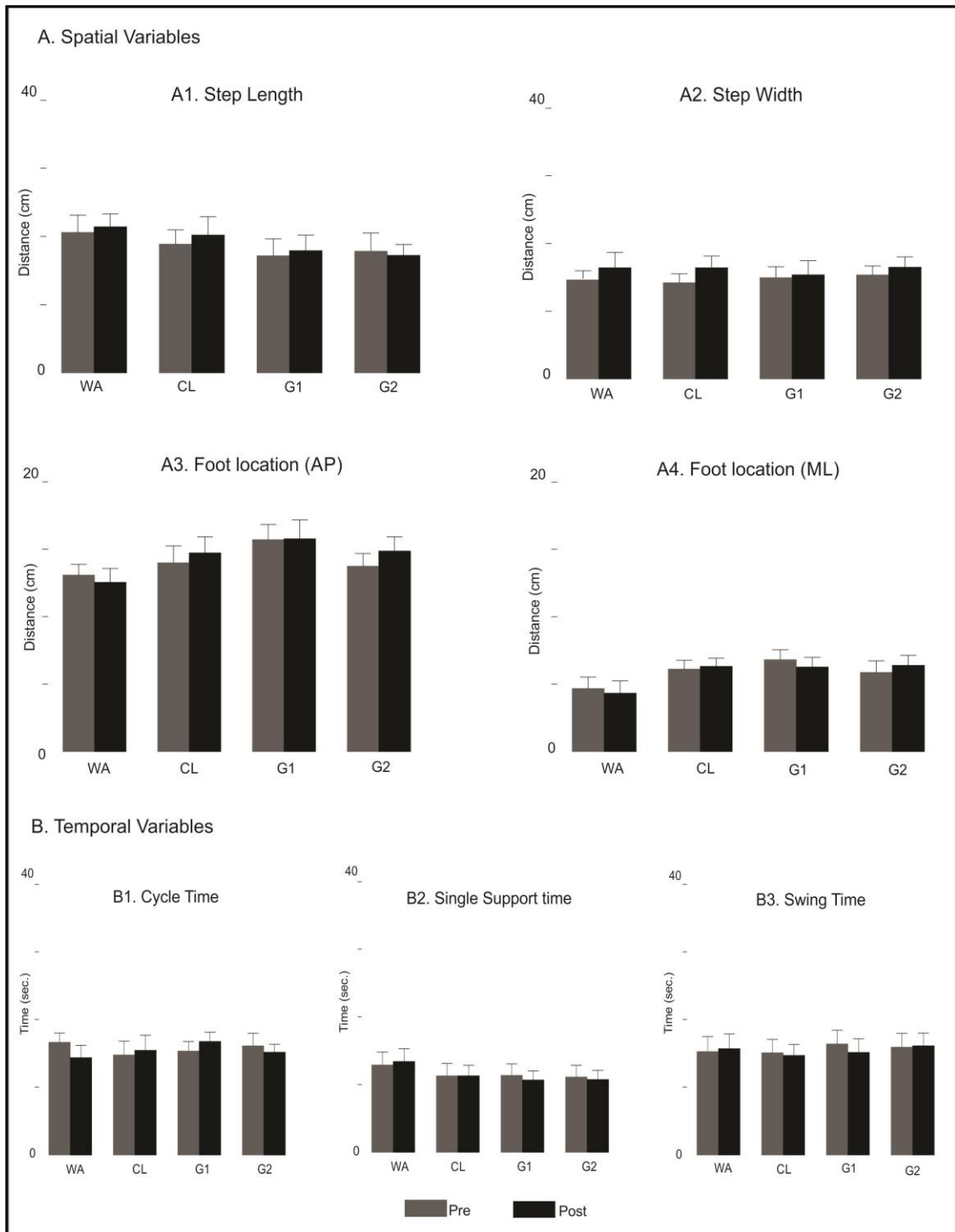


COP: centre of pressure; ML: medial-lateral; AP: anterior-posterior; EO: eyes open; CL: close loop; G1: simple game; G2: moderate game; EC: eyes closed

4.3. Effect of Dual-Task Recumbent Bicycle Intervention on Spatial-Temporal Gait Variables

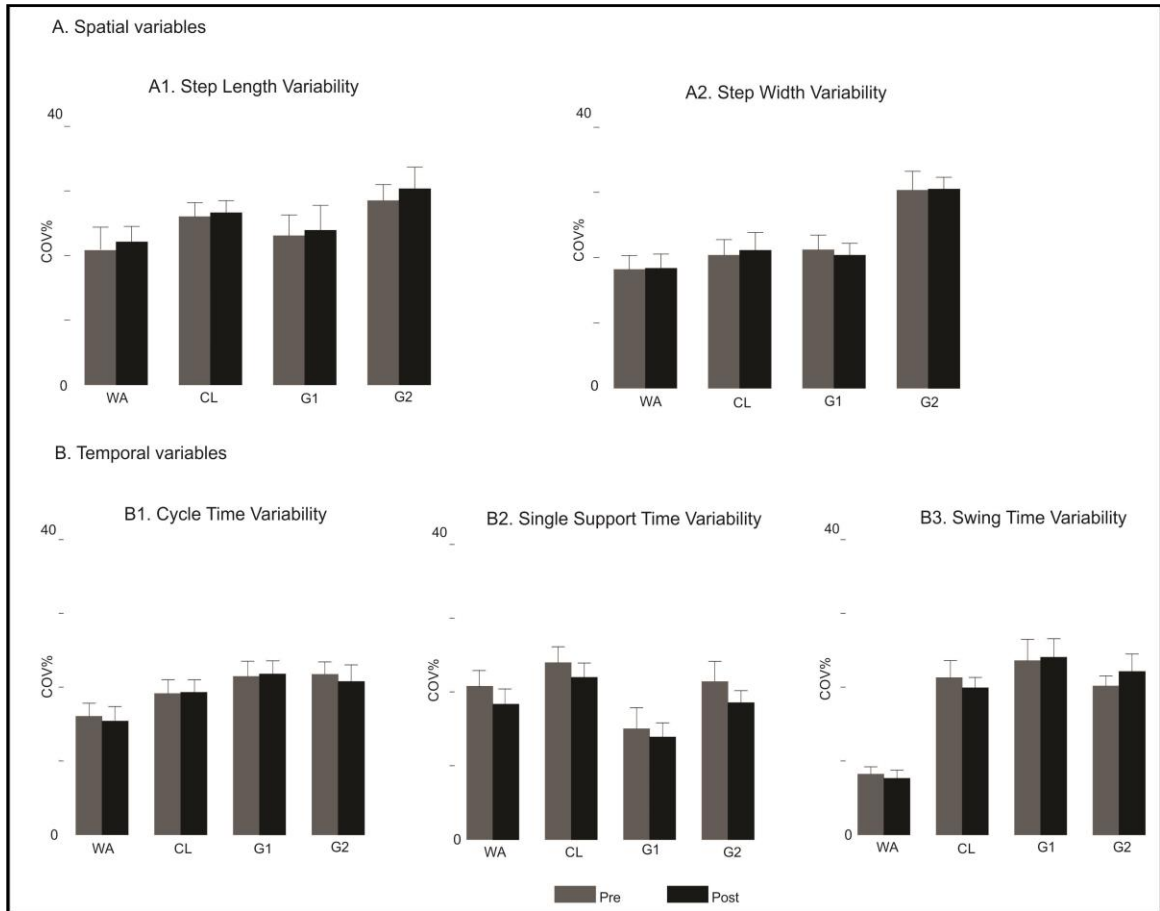
Figures 03 and 04: Present the group means and SEM for the averaged and COV of spatial-temporal gait variables before and after the intervention performed while control walking and dual-task walking. Results of paired t-test revealed that there was no significant effect of the intervention on spatial-temporal gait variables (average or COV).

Figure 03: Presents the group means and SEM for averaged spatial-temporal gait variables before and after the intervention. A. Spatial variables; B. Temporal variables



ML: medial-lateral; AP: anterior-posterior; WA: walk alone; CL: close loop; G1: simple game; G2: moderate game

Figure 04: Presents the group means and SEM for COV of spatial-temporal gait variables before and after the intervention. A. Spatial variables; B. Temporal variables



WA: walk alone; CL: close loop; G1: simple game; G2: moderate game

4.4. Effect of Dual-Task Recumbent Bicycle Intervention on Visual Tracking

Performance

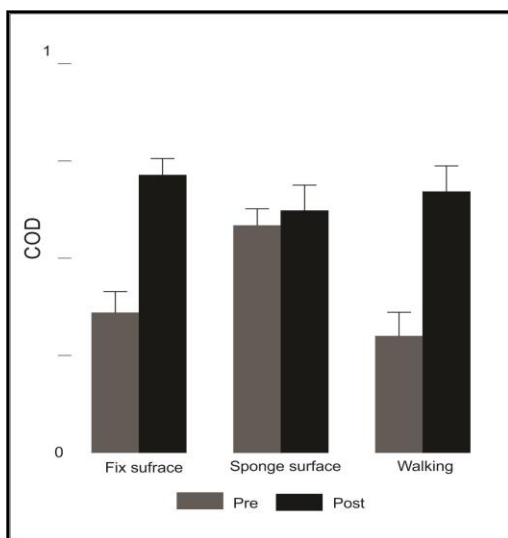
Figure 05: Presents the group means and SEM for COD before and after the intervention performed while standing and walking. As presented in Table 04, the results of paired t-test revealed that there was a significant increase in head tracking performance from pre to post intervention while standing on fixed surface as well as walking. However, there was no significant effect of the intervention in head tracking performance while standing on sponge surface.

Table 04: Presents paired t-test results for COD scores performed on different physical conditions

Conditions	Paired t-test
fixed surface	0.002 (4.058, 10)
Sponge surface	NS
Walking	0.002 (4.091, 10)

Significant: $p < 0.05$; NS: Not Significant

Figure 05: Presents the group means and SEM for COD scores while standing as well as walking on the treadmill before and after the intervention.



COD: coefficient of determination

4.5. Effect of Dual-Task Recumbent Bicycle Intervention on Cognitive Game Task Performances

Figures 06 and 07: Present the group means and SEM for success rate, response time, and execution time before and after the intervention while playing simple cognitive game (target-plus-distractor) and moderate cognitive game (target-plus-diagonal-distractor).

Results of paired t-test revealed that there was a significant increase in success rate of moderate cognitive games (target-plus-diagonal-distractor) from pre to post intervention when performed on the fixed surface ($P < 0.002$, $t = 3.878$, $df = 10$), sponge surface ($P < 0.000$, $t = 4.378$, $df = 10$), and walking ($P < 0.001$, $t = 3.798$, $df = 10$). There was no significant effect of the intervention on response or execution times. There was no significant effect of the intervention in the success rate, response time and execution time of the simple cognitive game (target-plus-distractor).

Figure 06: Presents the group means and SEM for A. Success rate; B. Response time; C. Execution time, before and after the intervention while performing simple cognitive game during different physical loads.

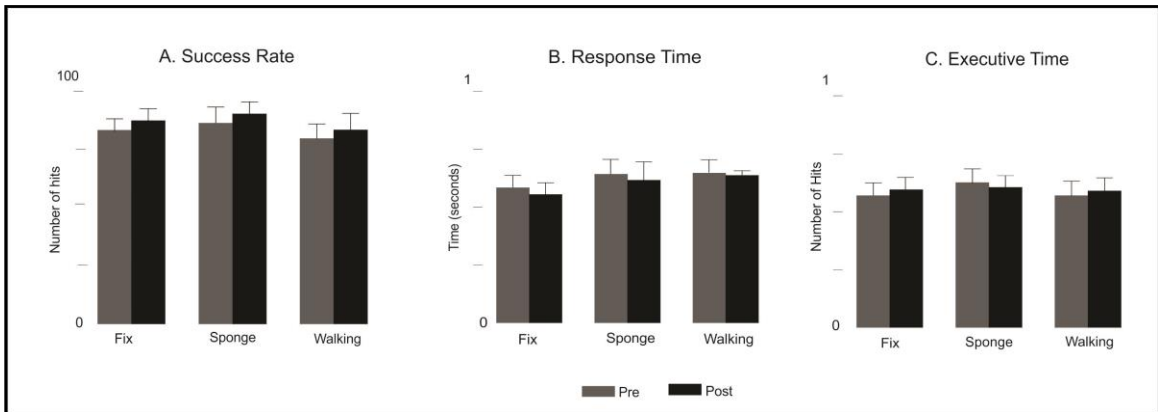
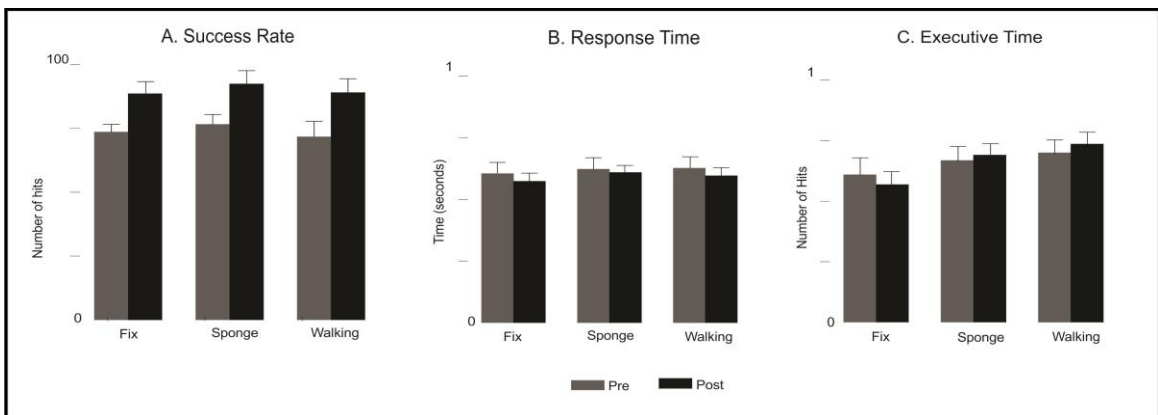


Figure 07: Presents the group means and SEM for A. Success rate; B. Response time; C. Execution time, before and after the intervention while performing moderate cognitive game during different physical loads.



4.6. Effect of Dual-Task Recumbent Bicycle Intervention on Neuropsychological Measures

As presented in Table 05, the results of paired t-test revealed that there was a significant decrease in the time recorded for the Trails Making Test from pre to post intervention when tested while sitting. Neither the visual search nor the verbal fluency showed any significant effect of the intervention.

Table 05: Presents results of group means, SEM and paired t-statistics for visual search, verbal fluency and TMT (A and B) before and after the intervention.

Conditions	Means± SEM (pre)	Means± SEM (post)	P-value (t-statistics, df)
Visual search			
-Right (30)	17.90±2.11	18.54±1.78	NS
-Left (30)	15.63±2.06	18.90±1.95	NS
-total (60)	33.54±3.99	37.63±3.65	NS
Verbal fluency			
- F (25)	13.90±1.03	15.18±1.16	NS
- S (25)	12.36±1.15	12.54±1.46	NS
- A (25)	14.09±0.85	16±1.31	NS
- Animal (25)	14±2.03	16.54±2.04	NS
TMT-part A	51.81±3.98	43.18±3.98	0.01(3.135, 10)
TMT-part B	118.81±10.86	102.54±7.43	0.004(3.745, 10)

TMT: trail making test; SEM: standard error mean; df: degree of freedom; Significant: $p < 0.05$ (Bonferroni adjusted $P \leq 0.01$); NS: Not Significant

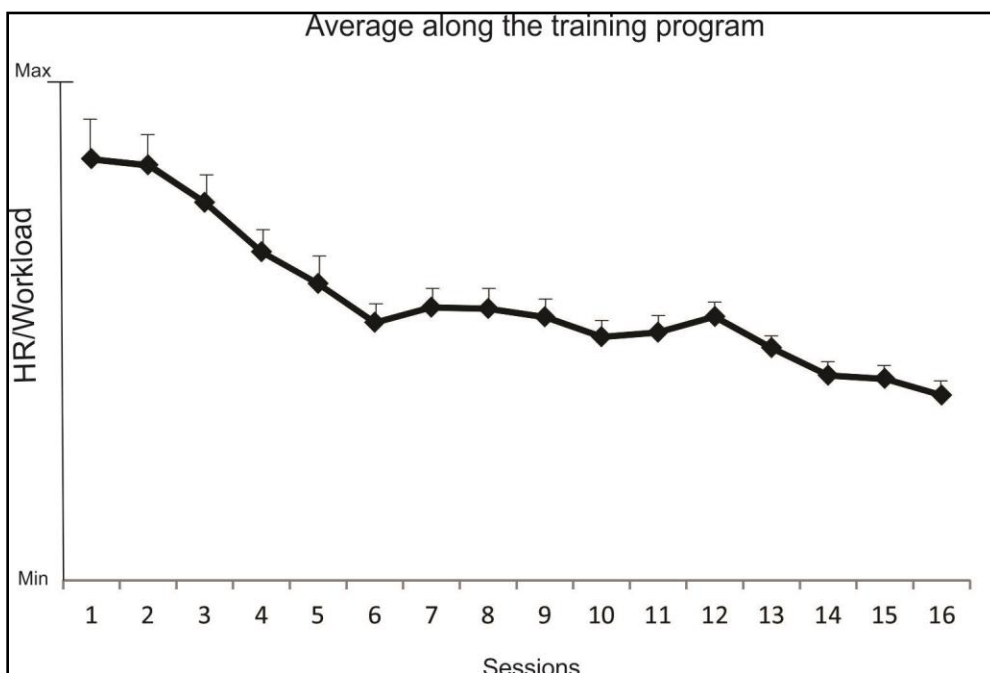
4.7. Effect of Dual-Task Recumbent Bicycle Intervention on Cardiac Fitness

Figure 08: Presents the average for the heart rate per unit workload ratio along the dual-task recumbent bicycle intervention. It can be seen from the graph that the overall trend for the heart rate to workload ratio decreased by 44% over the 8-week of the dual task recumbent bicycle intervention.

The results of paired t-test from session 1 to 16 revealed that there was a significant decrease in the heart rate to workload ratio over the 8-week of the intervention ($P < 0.000$, $t = 5.938$, $df = 10$). There was a significant decrease in the heart rate to workload ratio

between the 1st session and the 6th session (phase 1) ($P < 0.000$, $t = 5.384$, $df = 10$). Also, There was a significant decrease in the heart rate to workload ratio between the 12th session and 16th session (phase 2) ($P < 0.03$, $t = 2.389$, $df = 10$).

Figure 08: Presents the average for the heart rate per unit workload ratio along the dual-task recumbent bicycle intervention



4.8. Effect of Dual-Task Recumbent Bicycle Intervention on Physical Performance

Tests

As presented in Table 06, the results of paired t-test revealed that there was a significant increase on walking distance while the average walking speed remains the same from pre to post intervention. There was a significant decrease in the time while performing five times sit to stand test from pre to post intervention.

Table 06: Presents results of group means, SEM and paired t-statistics for six minute walking test and five times sit to stand test before and after the intervention.

Conditions	Means± SEM (pre)	Means± SEM (post)	P-value(t- statistics, df)
6MWT speed (over a distance of 25 m.)	1.75±0.15	1.99±0.22	NS
6MWT distance (215.16 m./lap)	592.89±36.12	642.54±26.46	0.05(-2.204, 10)
5xSTST	12.63±1.12	9.36±0.84	0.000 (6.708, 10)

6MWT: six minute walking test; 5xSTST: five times sit to stand test; df: degree of freedom; Significant: $p < 0.05$; NS: Not Significant

4.9. The Feasibility of Dual-Task Recumbent Bicycle Intervention

Seven out of eleven participants were interviewed individually; the other four participants did not answer the phone call. Table 07: Presents selected significant statements reported by the participants. Five common themes emerged from the interviews. The most common themes that emerged from the interview were as follow: 1) The exercise program was appropriate, flexible, and achievable; 2) cognitive games engaging and motivating; 3) perceived exercise benefits; 4) perceived difficulties with the exercises and using the technologies; 5) Recommendation and comments.

Table 07: Selected significant statements informed by the participants

Significant statements	Emergent themes
<ul style="list-style-type: none"> • I think that they were useful, when I was doing it. • The exercises seemed to be reasonably well designed. • I never done exercise like this before and Absolutely, I will do it again so (stop seeing TV and start playing games. • The training sessions were adequate and I would like to continue doing this type of program again. • I was fully satisfied as my balance improved somehow. • The sessions were suitable and I was happy doing this exercise. • I have a balance issue and I think that this exercise was good to start with. • I would like to be involved in this type of programs in the future because it keeps me focused. 	<p>Theme 01 The exercise program was appropriate and doable</p>
<ul style="list-style-type: none"> • Eyes and head coordination and how they relate to your mind when you do different things was amazing. • I didn't like Action ball, but I like Aquaball, Piglet, Birds town, Butterfly, and Majoung. • The way that get you really involved (games) and how involve your brain alert was wonderful. • I need to spend more time to understand the game and do my best. • I did not like the games but I played them to get the benefit, most of the games were very challenging to me. • The games were fully engaged me and made me conscious and more concentrate in what I'm doing. • I liked all the games especially "Bejeweled"; I hate "brave Piglet" • I was fully engaged and fully concentrate. • I like all the games, and they were fun and enjoyable. • The games were fully engaged and I understand that you use it to train my mental skills. 	<p>Theme 02 cognitive games engaging and motivating</p>

Significant statements	Emergent themes
<ul style="list-style-type: none"> • Games helped me to be motivated during the session. 	
<ul style="list-style-type: none"> • Made me more aware of my surroundings (mind alert while walking. • After playing those games I become aware of my surroundings. • After the training there is something happen that I don't know, my balance improved and it made me more aware about the surrounding. • I think that this program would help my thinking and balance. • Wanted to know how the games would benefit and progress my mental skills. • My balance improved somehow. • Doing this type of exercise helped me to be more focused. 	<p>Theme 03 Perceived exercise benefits</p>
<ul style="list-style-type: none"> • It was difficult but as long as you concentrate you are ok. • Cycling was not really difficult, but games were challenging. • The exercise was not easy at all, I need to focus, concentrate, and it is like chewing the gum and talking at the same time. • The screen was high for me, otherwise, everything was good. • The program was easy. • I obviously had some difficulty with some of the games. • I don't think I had any problems with the program, I think it was easy to handle. 	<p>Theme 04 perceived difficulties with the exercises and using the technologies</p>
<ul style="list-style-type: none"> • Highly recommend this exercise and should advertise. • This is really good training program, you should commercialize it. • The screen was high. • The program should be more physically emphasized (including the weight). • You need aboard on the side to give us more control using the clicker. 	<p>Theme 05 Recommendation and comments</p>

4.9.1. Textural description

Each interview transcript was reviewed and reported as textural description which includes brief explanation of the individual responses. The responses coded into themes supported by a few key quotes: Theme 01: the exercise program was appropriate, flexible and achievable: 7 participants reported that the exercises were adequate, reasonably well designed and practically achievable without any difficulty. For example, one participant reported that “I never done exercise like this before and Absolutely, I will do it again so - stop seeing TV and start playing games”. Theme 02: cognitive games engaging and motivating: 7 participants reported that playing computer games helped them engage with their sessions and even listed some of their very favorite games. There was strong agreement that everyone enjoyed playing a different variety of games, some which were also challenging. For example, one participant stated that “The games were fully engaged me and made me conscious and more concentrate in what I’m doing”, “I liked all the games especially “Bejewelled”; I hate “brave Piglet”. Theme 03: perceived exercise benefits: 7 participants described the exercise program as beneficial. For example, a participant reported that “After the training there is something happen that I don’t know, my balance improved and it made me more aware about the surrounding. Theme 04: perceived difficulties with the exercises and using the technologies: 7 participants identified this type of training program as suitable, but they had some difficulties doing some challenge games. For example, one participant reported that “It was difficult but as long as you concentrate you are ok.” Another participant stated that “Cycling was not really difficult, but games were challenging.” Theme 05: recommendation and comments: 5 participants recommend the intervention program and they like to do it again but with

some modifications. For example, a participant reported that “This is really good training program, you should commercialize it.” Also, 3 participants understood the dual task treadmill walking effect on balance and they prefer to do it instead of the dual-task recumbent bicycle intervention.

5. DISCUSSION

The primary purpose of this pilot study is to examine the benefit of the game based DT-RC intervention; to examine the feasibility of the DT-RC intervention on healthy older adults who live in the community and attend the Reh-Fit centre for exercise.

The first primary objective was to examine the effect of intervention on balance, mobility, gaze, cognition, and cardiac fitness.

Standing core Balance: A COP excursion was used to assess core balance while standing on fixed surface as well as sponge surface. Several studies have examined the maintenance of standing balance under sponge surface with eyes closed situation, and it was observed that there was a significant increase in body sway [58, 71]. Also, several other studies have demonstrated that the head tracking performance increased body sway [107, 127, 128]. The results of the current study manifest that the intervention had a positive effect on COP excursions when assessed on sponge surface with the addition of head tracking task. On the other hand, our intervention did not affect the COP excursions when assessed on fixed surface. Also, we observed that the number of participants who loss of balance (LOB) after the intervention decreased with the eyes closed sponge condition.

There is some explanation as to why the COP excursions might be improved with the intervention on the head tracking sponge condition. One explanation is that the cognitive training games used for the training involved rapid visual tracking while producing head rotations. The cognitive games required head tracking while cycling. Thus, the dual-task performance would improve while testing the participants on the

sponge surface. Our conclusion that the core balance of participants did not change is based on the fact that following the training program; there were no significant changes in balance during the fixed surface test. Also, the eyes open condition, as per CTSIB did not change significantly from pre to post DT-RC intervention. An interesting finding of the current study was that during the eyes closed sponge condition, the participants exhibited an increased frequency of balance loss prior to the intervention. However, following the intervention the number of participants who LOB decreased by 50%. This finding is very important; however, it is not clear why this occurred.

Five times sit to stand test improved significantly after the training. This test was used to examine physical ability in terms of the lower limbs function and balance. The improvement in lower limbs function was expected as a result of cycling training; this is similar to the findings reported by previous studies done by Zhang et al., 2013; Goldberg et al., 2012 [129, 130]. The improvement in lower limb function, in addition to the visual tracking improvement mentioned above could be another factor impacting the COP excursions improvement on the sponge surface observed after conducting the program.

Spatial-temporal gait variables: Average and COV of the spatial-temporal gait variables were used to examine the effect of DT-RC intervention on gait performance. The results for the spatial and temporal parameters did not show any significant intervention effects. The treatment program did not include the walking task. Thus, the gait training was not the main focus of the treatment. The intervention program was performed with a recumbent bicycle and focused on dual-task training. Previous studies have suggested that in order to improve gait performance, the exercise program must include walking activities [1, 131, 132].

Head tracking performance: The current findings showed that there was a significant improvement post-intervention on head-tracking performance while standing on fixed surface and during treadmill walking. The participants were instructed to play a variety of computer games while cycling. These computer games required rapid visual search and tracking, while producing head rotations to reposition the game sprite with respect to game targets while avoiding distractor objects. Previous studies have demonstrated that gaze stability training involving active or passive head rotation while focusing on stationary visual targets resulted in an improvement of dynamic visual acuity [133-135]. Improved gaze performance of the visual tracking test in standing post-intervention may be attributed to the improved smooth pursuit or use of catch-up saccades. Also, the gaze performance improved in post-intervention walking. Dual-task walking required increased passive head movement with unpredictable characteristics, which require VOR compensation to maintain gaze stability [136, 137]. In this respect, improved gaze performance of head-tracking test during treadmill walking post-intervention is likely due to VOR adaptation in combination with improved smooth pursuit.

Cognitive task performance: Dual task cognitive measures were used to examine the cognitive executive functions (i.e. speed of processing and cognitive inhibition) while standing as well as while walking. Results indicated a significant increase in success rate in moderate cognitive game (target-plus-diagonal-distractor) while standing as well as during walking; however, the intervention did not affect the response time and the execution time. With respect to neuropsychology tests, the effects of the intervention were primarily observed in the TMT (A and B). The test is used to assess the mental flexibility function, and our results suggested that the participants needed less time to

complete this test. This finding is similar to previous research that supports the utility of brain exercises to facilitate cognitive executive function in older adults [14, 57, 68-72, 83]. For our study, we hypothesized a significant intervention effect on visual search test since the cognitive training games used by us included some characteristics for this task. However, there was no significant change in visual search test. We did not expect any change for the verbal fluency test as our cognitive training games did not include content related to that aspect.

We used a number of cognitive training games that required visual-spatial processing as well as executive cognitive functions. The cognitive games that were used involved executive function characteristics including speed of processing, distraction avoidance, enhancing decision making, and visual search. Our findings suggested that the use of cognitive games in addition to physical activity (i.e. cycling) in a program would enhance and influence the mental flexibility performance. Most of the gameplay elements required game sprite movement and head rotation. These movements were often rapid. There were different elements that required executive functions, in terms of processing speed, cognitive inhibition, and visual search. These included: 1) the game sprite that was controlled using head rotations; 2) the game target to interact with; 3) distractor objects that needed to be ignored, and 4) other objects that required special attention such as complex background. Participants were required to rotate their heads to control the game sprite and to foveate and track a certain target while avoiding distractors.

Anderson-Hanley et al., 2012 [101] found that cycling exercise alone did not improve the cognitive executive function. However, when coupled with cognitive exercise, cycling exercise promotes processing speed. Thus, cognitive executive

performances of the participants become better. Overall, the results of the current study confirm and extend previous results and demonstrate that, in addition to the benefits observed in cognitive executive function (i.e. mental flexibility), the intervention also had a greater impact on cardiac fitness guided by the heart rate to workload ratio. At the same time, executive functioning, as indexed by performance on the TMT, improved significantly after the training incorporated in this program.

Cardiac fitness: Findings of the current study indicated that the intervention led to a 44% increase in cardiac fitness level. This suggests that even for the individuals falling in the age range of 70-80 years, engaging in dual-task paradigm delivered strong benefits in terms of cardiac fitness. Research in this area has shown that aerobic exercise can exert a positive influence on cardiac fitness in older adults [88, 138]. Also, research has shown that moderate levels of physical activity guided by heart rate to workload ratio are critical for efficient cardiac fitness [85, 86]. For example, Baker et al., 2010 [93] reported that aerobic exercise at 75%-85% max heart rate indicated a significant improvement in cardiac fitness. Our dual-task intervention showed that eight weeks of moderate intensity aerobic training at 60% of maximum heart rate improved cardiac fitness.

The second primary objective was to examine the feasibility of the DT-RC training program by understanding participants' lived experiences who have completed the program. The quantitative findings were supported by participants' lived experience during the DT-RC training program. Additionally, several identifiable themes emerged to provide more depth in understanding the findings.

Participants completed the program and agreed that the intervention was well-designed and appropriate. Five of the participants reported that some computer games were difficult to understand and they had to spend some time (around 15-20 minutes) during the first two sessions to understand and learn the goal of the games. The dual-task aspect was an issue when they started the intervention as they found it difficult to control the gameplay and cycle at the same time. The examiner helped the participants understand how to control the gameplay. Also, the examiner assisted the participants by furnishing them instructions on how to play the games by rotating the head. Once they understood what was required to be done, they found the training program suitable and the use of equipment easy. Participants reported that the examiner's instructions were easy to follow.

The possibility of using dual-task recumbent bicycle training program in the community among older adults is appealing for many reasons: First, participants tend to enjoy what they are doing. Another benefit of the intervention is the low cost for the entire system. The recumbent bicycle with screen display is available in community centers and the games used for the training program were inexpensive and available online. Also, the Gyration air mouse used for game control is available for retail purchase for under \$75. Another notable factor in this program was that the games provided feedback for the participants with regard to their game performance. This is important for the clients' rehabilitation, as it helps the participants to be active, and also requires the clinician to provide feedback for clients and encourage them to perform better.

There was a strong agreement amongst the participants that they enjoyed playing different games in the program. For instance, one participant stated that "eye and head

coordination and how they relate to your mind when you do different things was amazing”. Another participant reported that, “The games made me conscious in what I’m doing”. Each participant played at least eight computer games that were selected from a pool of commercial games purchased from Big Fish Games (www.bigfishgames.com). The most common computer games that were used for all the participants were “Action Ball”, “Aquaball”, “Bejewelled”, “Birds Town”, “Brave Piglet”, “Jet Jumper”, and “Feeding Frenzy”. These games required visual search, processing speed, and cognitive inhibition while rotating the head at the same time. At the beginning of the program, games were selected with respect to slow target movement, fewer distractors, and simple background. However, later in the program, game speed, number of distractors, and features were advanced as per the participants’ tolerance.

The Gyration air mouse was secured to helmets worn by the participants and was used to control the computer games using head rotation. Some games were difficult to be controlled using head pointing movements as they required generalized movements (i.e. moving the head right/left and up/down). Other games required precise and fine movements. In all cases, the examiner set the game sprite at the centre of the screen using Windows platform setting, and instructed the participants to look at the centre of the screen. After that, the examiner instructed the participants to rotate their heads smoothly without any jerks to control the game sprite. If the mouse cursor drifted during the play, the examiner calibrated and adjusted the game sprite at the centre of the screen. The drift caused by jerky head movements led to misalignment of the mouse cursor. This led to the finding that the mouse cursor was at the edge of the screen, while the participant was focused at the screen’s center. This caused certain difficulty while playing the game,

which could be easily avoided by avoiding jerky head movements. However, this was an indication that there was a need for advanced technological products with better cursor stabilization to prevent drifting.

Participants indicated that playing computer games helped them become more engaged during their sessions. This is similar to the findings reported by Strenziok and his colleague (2014) [83]. The games that were used varied between action games, matching games, and tracking games. Most of the participants enjoyed playing action games as their cycling speed increased. However, while playing matching games or puzzles, they slowed to focus on the game. Also, the participants were highly keen on knowing how to deal with the games and on how to win the games. Some of the participants had difficulty understanding some of the games, and they expressed their displeasure at the same. While the others made a laudable effort at comprehending the games by accepting it as a challenge. Some participants reported that they could not make out why they were playing those games, and how those games would benefit their balance. However, most of the participants understood what cognition training meant and suggested to the examiner to play certain games like “Bejewelled” and “Birds Town” as they thought those games would aid in enhancing concentration and focus.

Most of the participants described the program as beneficial and motivating, especially as they experienced gradual improvement in their daily life. For instance, one of the participants reported that he was better aware of the surroundings while walking around the track in the Reh-Fit Centre rather than feeling disoriented and deviating from the track while hitting other walkers. Another participant reported that he was able to wake up and go to the washroom in the morning without losing his balance or holding on

to the wall. The results of the current study showed that the DT-RC training program had a significant effect on dual-task functions. Also, the results showed that the mental flexibility functions improved after the dual-task training program. Thus, these findings are clinically important, showing an improvement in the cognitive performance in addition to the physical activity performance in older adults. Additionally, our participants reported that their physical activities performance, in term of exercising, become better after the intervention. This finding is clinically relevant, showing an increase in the potential impact of the cardiac fitness in older adults.

No simple conclusion can be drawn regarding the observation of increases in some performance of functional tasks, including the cognitive and physical functions, following the DT-RC training program. This encourages future development of intervention that can promote dual-task functioning and performance of daily life.

6. CONCLUSION

In conclusion, this pilot study showed that the newly designed game-based dual-task training program was feasible and demonstrated a beneficial impact on gaze performance, mental flexibility function and cardiac fitness among healthy older adults who lived in community.

The DT-RC training program had a beneficial effect on the gaze stabilization under dual-task conditions while standing as well as walking. However, the cognitive executive function (i.e. mental flexibility) improved only while sitting. Finally, the DT-RC training program also had an impact on cardiac fitness. Blended approach of balance, mobility, gaze and cognition will contribute to better understanding of the decline in the physical and mental skills with age.

Clinical Significance

The current study presents significant information on successfully implementing the novel dual-task intervention in the community, and provides evidence on the feasibility and acceptability of the dual-task training program. Also, it emerges that the dual-task intervention was beneficial on dual-task skills and cardiac fitness among older adults. The interactive nature of the dual-task training program requires that participants be motivated and be active to win the game, which is an important factor for rehabilitation. The platform and tools were designed to provide client-centered programs of rehabilitation and for the progression from supervised to unsupervised community programs.

Aerobic exercise is a cost-effective practice that is associated with numerous physical benefits such as cardiac fitness. The results of this study revealed that the dual-task recumbent bicycle exercise also provides a cognitive benefit for older adults. Future longitudinal intervention studies involving regular intervals of increased heart rate coupled with cognitive training would be sufficient to improve cognitive performances. A number of studies carried out by Erickson et al., (2010); Aarsland et al., (2010); Middleton et al.(2010); Swain et al., (2003); and Verdelho et al., (2010) [9-12, 91], showed that the aerobic exercises can promote cerebral blood flow, which enhances neurogenesis and improves learning as well as promotes cardiac fitness, which is important for slowing the rate of cognitive impairment. There are indications that the intensity rather than the duration of physical activities would be beneficial for cognition, which may have implications for the effectiveness of the training program [87].

Limitations

1. Although the study results are encouraging and indicative of program feasibility, one needs to interpret these results with caution from a study with a small sample size. The present findings will need to be further validated with findings from a RCT with a large population.
2. Another limitation of this study is the difficulty to generalize our data because of the small sample size as well as our participants were healthy older adults.
3. A further limitation of this study is the absence of a control group to understand the full impact of the programme.

4. The lack of long term follow up limits the ability to determine whether the benefits of the intervention were retained, as well as the ability to understand the impact the dual task training has on risk of falling.

Future Directions

1. Since fall prevention is an important goal of dual task interventions, future studies should consider incorporating cognitive tasks in combination with walking in their protocol and outcome measurements.
2. There is a need to further examine the effect of different cognitive-motor training, and the interaction between them, on dual task acquisition, retention and transfer. These might include the influence of instructions, the specificity of training, and the effect of dose on the response to training.
3. Further exploration is needed to determine the efficacy of training within subgroups of older adults, such as those with or without a history of falls or with different cognitive abilities.
4. Future studies are needed to progress the program from supervised to unsupervised community programs.
5. In order to strengthen the evidence based for improving dual task performances, future studies should include larger, more representative samples and use standard set of outcome measures to allow randomized clinical trials and cross study comparison.
6. Moreover, long term follow up with regard to fall occurrence and daily functions should be incorporated in order to better understand whether or not improved dual task performance impact these areas.

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APPENDICIES

Appendix 01: Experimental set-up. The recumbent bicycle with a computer monitor



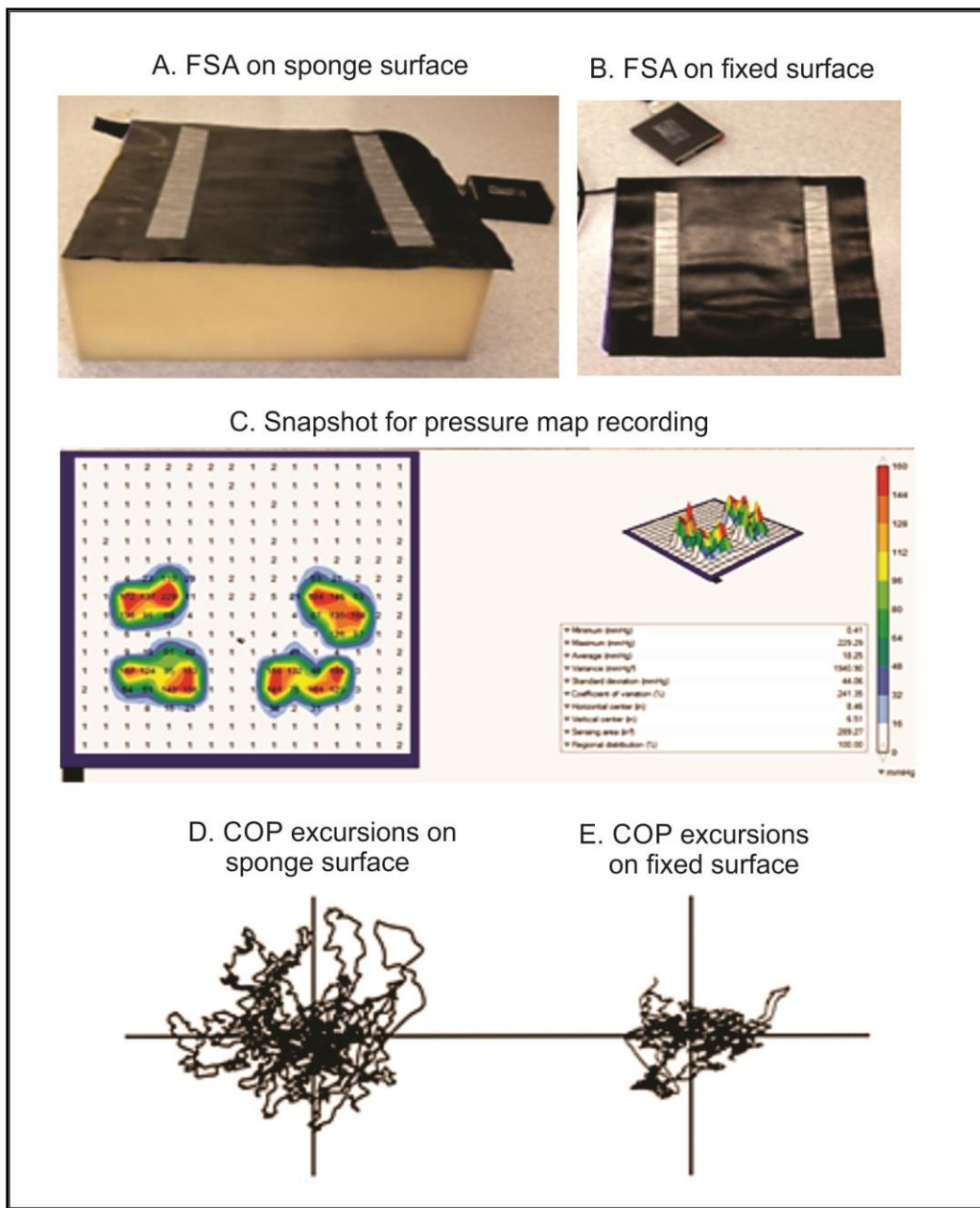
Appendix 02: Spree Fitness Monitor



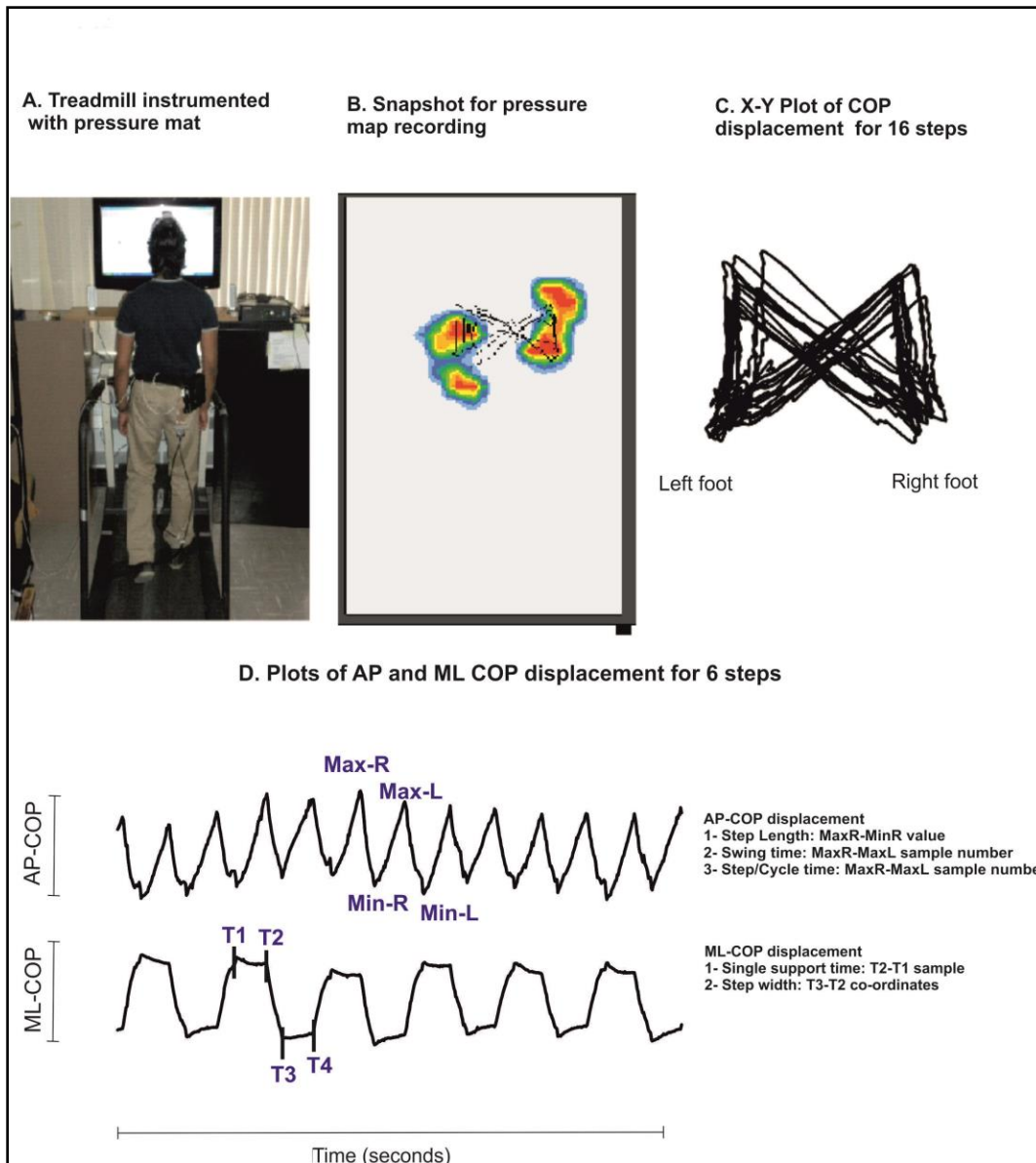
Appendix 03: Gyration air mouse



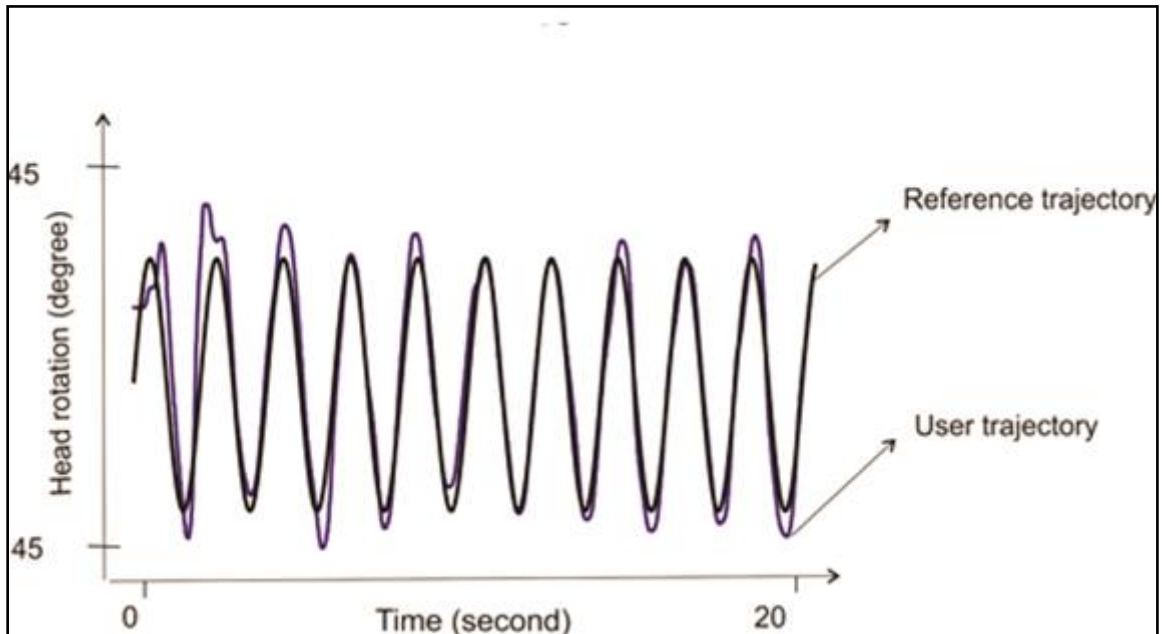
Appendix 04: Presents COP excursions in AP and ML directions under different physical conditions. A & B. Presents sponge and fixed surfaces with FSA pressure mapping system. C. Presents a snapshot for pressure map recording. D & E: COP excursions on sponge and fixed surfaces.



Appendix 05: Testing set-up. A: Presents a participant walking on treadmill while viewing a computer monitor and using motion mouse (head rotation). B: Presents a snapshot of pressure mat recording vertical force during walking. C: Presents X–Y plots of COP displacement for 16 steps. D: Presents AP and ML COP time series data for 6 steps



Appendix 06: Presents synchronous plots of the reference (computer) cursor motion and user movement trajectories (head rotation) for a typical tracking task. Similarity between trajectories signifies performance.



Appendix 07: Cognitive game analysis. A: Presents the trajectory of game paddle movements (head rotation) for one logged game file. B: Presents the overlay of individual game events segmented. C: Presents the sorted and grouped segmented game events. D: Presents the analysis methods to quantify success rate, response time, and execution time.

