

The effects of dual-task training on dual-task skills in older adults

By

Deborah Jehu

B.Kin., Brock University, 2010

M.Sc., Brock University, 2012

Thesis submitted to the

School of Human Kinetics, Faculty of Health Sciences

in partial fulfillment of the requirements for the

Doctorate in Philosophy degree in Human Kinetics

University of Ottawa

© Deborah Jehu, Ottawa, Canada, 2017

ABSTRACT

It is well established that aging is associated with numerous health concerns, including poor balance. Deteriorations in attention demand also place older adults at a greater risk for falls. Emerging experiments have explored the impact of dual-task training programs and have improved dual-tasking in older adults. However, it is unknown whether these performance-related improvements are a function of the intervention itself or the repeated exposure to the testing protocol. Study 1 explored the implications of repeated administration, once per week for 5 weeks, of a protocol involving standing postural sway while concurrently performing reaction time (RT) tasks in older adults. Results revealed that postural sway was stable across testing sessions whereas the difficult RT task gradually improved over time. Study 2 examined the influence of repeated exposure, once per week for 5 weeks, of a protocol involving negotiating a series of obstacles while performing RT tasks in older adults. Participants walked significantly faster with repeated exposure and gradually improved RT. Study 3 investigated the impact of repeated exposure, once per week for 5 weeks, to three functional mobility measures in older adults. It also examined the influence of a 12-week balance and mobility training (BMT) program as well as a 12-week balance and mobility plus cognitive training (BMT+C) program on functional mobility in older adults. Functional mobility served to be stable over time. Both the BMT and BMT+C groups significantly improved functional mobility and sustained these improvements at the 12-week follow-up, while no changes were observed in the control group. No differences between the BMT and BMT+C groups emerged. Experiment 4 examined the influence of BMT and BMT+C on postural sway and RT in older adults. Participants in both training groups significantly improved RT and sustained these improvements at the follow-up, while no changes were observed in the control group. No changes to postural control were shown

in any group. No differences between the BMT and BMT+C groups emerged. Experiment 5 examined the influence of BMT and BMT+C on negotiating a series of obstacles while performing RT tasks in older adults. Both the BMT and BMT+C groups significantly improved RT and sustained these improvements at the follow-up, while no changes were observed in the control group. All groups showed faster time to completion of the obstacle series. No differences between the BMT and BMT+C groups emerged. Collectively, these findings suggest that BMT and BMT+C significantly improve functional mobility and divided attention, and sustain these improvements over time. Although some improvements were observed after repeated exposure over 5 weeks, no changes in the control group were observed. Therefore, the improvements exhibited from BMT and BMT+C are likely not a function of repeated exposure to the testing protocol, as participants may be more susceptible to performance-related improvements when the testing sessions are close in proximity. Altogether, these findings propose that, whether or not cognitive training is included, attention demanding dual-task training not only improves functional mobility and RT, but also sustains these improvements over time in older adults. These results may be used to improve the prescription of exercise in older adults.

TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGEMENTS	xi
PREFACE	xiii
LIST OF ABBREVIATIONS	xv
LIST OF TABLES	xvi
LIST OF FIGURES	xviii
CHAPTER 1: GENERAL INTRODUCTION	1
Canada’s aging population	1
Impact of falls in older adults on the health care system	1
Role of aging on postural sway	2
Role of aging on functional mobility	3
Role of aging on obstacle clearance	4
Role of aging on attention demand	5
Effectiveness of dual-task interventions on balance and cognition in older adults	7
<i>Dual- compared to single-task training benefits in older adults</i>	9
<i>Effects of dual-task training on transfer effects in older adults</i>	15
<i>Effects of cognitive-cognitive dual-task training interventions in older adults</i>	19
<i>Summary of dual-task training literature in older adults</i>	19
Maintenance of dual-task training improvements at the follow-up	20
Caution when interpreting significance from balance training programs	21
CHAPTER 2: RATIONALE, PURPOSE, RESEARCH QUESTIONS & HYPOTHESES 24	
Rationale	24
Purpose	25
Research questions and hypotheses	25
<i>Research question 1</i>	25
<i>Hypotheses for research question 1</i>	26
<i>Research question 2</i>	26
<i>Hypotheses for research question 2</i>	26
<i>Research question 3</i>	26

<i>Hypotheses for research question 3</i>	27
<i>Research question 4</i>	27
<i>Hypotheses for research question 4</i>	27
References	28
CHAPTER 3: STUDY 1	44
Examining the stability of dual-task posture and reaction time measures in older adults over five sessions: A pilot study	44
Abstract	45
Introduction	46
Methods	50
<i>Participants</i>	50
<i>Procedure</i>	50
<i>Data and statistical analyses</i>	51
Results	52
<i>Stability of COP measures over 5 sessions</i>	52
<i>Effect of the stance tasks on COP measures</i>	52
<i>Effect of the RT tasks on COP measures</i>	53
<i>Stability of RT over 5 sessions</i>	53
<i>Effect of the stance tasks on RT measures</i>	53
<i>Effect of the RT tasks on RT measures</i>	58
Discussion	58
<i>COP measures</i>	58
<i>Reaction time</i>	59
Conclusion	63
Compliance with ethical standards	63
<i>Disclosure of potential conflicts of interest</i>	63
<i>Research involving human participants</i>	64
<i>Informed consent</i>	64
Acknowledgements	64
References	65

CHAPTER 4: STUDY 2	68
Improvements in obstacle clearance parameters and reaction time over a series of obstacles revealed after 5 repeated testing sessions in older adults	68
Abstract	69
Introduction	70
Methods	74
<i>Participants</i>	74
<i>Procedure</i>	74
<i>Data and statistical analyses</i>	77
Results	80
<i>Effect of obstacle height and order on foot clearance</i>	80
<i>Effect of dual-tasking on obstacle clearance parameters</i>	82
<i>Consistency of obstacle clearance parameters over 5 testing sessions</i>	85
<i>Consistency of RT over 5 testing sessions</i>	85
Discussion	88
<i>Effect of obstacle height and order on foot clearance</i>	89
<i>Effect of dual-tasking on obstacle clearance parameters</i>	91
<i>Consistency of obstacle clearance parameters over 5 testing sessions</i>	93
<i>Consistency of RT over 5 testing sessions</i>	93
<i>Limitation</i>	95
Conclusion	95
Acknowledgements	95
Conflict of interest statement	95
References	96
CHAPTER 5: EXPERIMENT 3	98
Balance and mobility training with or without concurrent cognitive training improves the timed up & go (TUG), TUG cognitive and TUG manual in healthy older adults: An exploratory study	98
Abstract	99
Introduction	100

Methods	103
<i>Participants</i>	103
<i>Testing protocol</i>	105
<i>Intervention</i>	107
<i>Adherence</i>	111
<i>Preliminary study</i>	111
<i>Statistical analyses</i>	111
Results	112
<i>Effects of balance training</i>	112
<i>Effect of BMT+C on the TUGcog</i>	113
<i>TUG measures at the 12-week follow-up</i>	113
<i>Adherence, attrition and impact of the training programs</i>	113
<i>Preliminary study</i>	113
Discussion	117
<i>Effect of balance training</i>	117
<i>Effect of BMT+C on the TUGcog</i>	119
<i>TUG measures at the 12-week follow-up</i>	120
<i>Adherence, attrition and impact of the training programs</i>	121
<i>Limitation</i>	122
Conclusion	122
Compliance with ethical standards	122
<i>Disclosure of potential conflicts of interest</i>	122
<i>Research involving human participants</i>	123
<i>Informed consent</i>	123
Acknowledgements	123
References	124
CHAPTER 6: EXPERIMENT 4	129
Balance and mobility training with or without concurrent cognitive training does not improve posture, but improves reaction time in healthy older adults	129
Abstract	130

Introduction	131
Methods	132
<i>Participants</i>	132
<i>Procedure</i>	133
<i>Data analysis</i>	135
<i>Intervention</i>	136
<i>Statistical analyses</i>	139
Results	139
<i>Baseline postural and RT characteristics between groups</i>	139
<i>Effect of Group, Session, and Group x Session interactions on postural measures</i>	139
<i>Effect of Group, Session, and Group x Session interaction on RT</i>	140
Discussion	143
<i>Main findings</i>	143
<i>Effect of balance training on posture</i>	143
<i>Effect of BMT+C on posture and RT</i>	144
<i>Limitations</i>	146
Conclusion	146
<i>Conflict of interest statement</i>	146
<i>Acknowledgements</i>	146
References	147
CHAPTER 7: EXPERIMENT 5	151
Balance and mobility training with or without simultaneous cognitive training reduces attention demand but does not improve obstacle clearance in older adults	151
Abstract	152
Introduction	153
Methods	155
<i>Participants</i>	155
<i>Procedure</i>	155
<i>Data analyses</i>	161

<i>Intervention</i>	161
<i>Adherence</i>	165
<i>Statistical analyses</i>	166
Results	167
<i>Baseline obstacle clearance parameters and RT characteristics between groups</i>	167
<i>Effect of balance training on balance and cognition</i>	167
<i>Effect of balance training on obstacle clearance parameters</i>	167
<i>Effect of balance training on RT</i>	168
Discussion	171
<i>Main findings</i>	171
<i>Effect of balance training on obstacle clearance parameters</i>	171
<i>Effect of balance training on RT</i>	173
<i>Limitations</i>	175
Conclusion	176
Conflict of interest statement	176
Acknowledgements	176
References	177
CHAPTER 8: GENERAL DISCUSSION	181
Summary of the main findings	181
Effects of repeated exposure to the testing protocol on postural sway, functional mobility, obstacle clearance parameters and attention demand (Research Question 1)	182
Effects of BMT and BMT+C on postural sway, functional mobility, obstacle clearance parameters and attention demand (Research Question 2)	184
Effects of the addition of cognitive training on postural sway, functional mobility, obstacle clearance parameters and attention demand (Research Question 3)	187
Effect of a 12-week follow-up on postural sway, functional mobility, obstacle clearance parameters and attention demand (Research Question 4)	188
Significant contributions	190
Limitations	195
<i>Sample population</i>	195

<i>Testing protocol</i>	195
<i>Training programs</i>	196
Conclusion	197
References	199
APPENDIX 1: COMPLETE LIST OF OBSTACLE COURSE TASKS AND LEVELS OF PROGRESSION	208
APPENDIX 2: EXAMPLES OF MANUAL TASKS	230
APPENDIX 3: COMPLETE LIST OF COGNITIVE TASKS AND LEVELS OF PROGRESSION	231
APPENDIX 4: COMPARISON OF RT ACROSS STUDIES 1-2 AND EXPERIMENTS 4-5	250
APPENDIX 5: NOTICE OF ETHICAL APPROVAL FOR STUDIES 1-3	251
APPENDIX 6: NOTICE OF ETHICAL APPROVAL FOR EXPERIMENTS 3-5	252

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisors, Drs. Yves Lajoie and Nicole Paquet, for their hard work and long hours of revisions during my PhD. Both of you have provided me with numerous opportunities to get involved in research outside of my dissertation, which has significantly improved my knowledge in the field as well as my publication record. Thank you both for providing me with wisdom and advice when I was searching for post-doctorate fellowships, as well as writing several reference letters over the years. Giving me many opportunities to present at conferences has brought me closer to my end goal of securing a position as an independent researcher. Yves, I specifically appreciated that you took the time to teach me technical skills, and improved my ability to critically appraise the literature in order to design innovative research. Nicole, I really value the countless hours you spent with me refining my writing skills such that my ideas flow logically. I am also forever grateful that you suggested and facilitated the visiting PhD student scholarship that I received at the Hong Kong Polytechnic University; I am sure that I will gain invaluable knowledge and skills through this experience. I believe that being co-supervised has benefited me to a greater extent as I have been able to learn from both of your strengths. Thank you both for taking me on as a student, the knowledge and skills I have learned will carry through my career.

I would also like to acknowledge my committee members, Drs. Martin Bilodeau and Heidi Sveistrup, my internal-external committee member, Dr. Diane Ste. Marie, and my external-external examiner, Dr. Richard Courtemanche. Thank you so much for your time and counsel, my thesis will be a much stronger document.

I would like to thank my participants. Participating in either the repeated testing procedures or taking part in the intervention or control group was a great time commitment. Getting to know

each and every participant was such an enriching experience for me. Without your contribution, this thesis would not be possible.

To all of my lab and graduate student friends, our social events, laughs, and unforgettable memories have definitely made this experience enjoyable.

I would also like to extend my sincerest gratitude to my parents, my brothers Dave and Mike, and my sister Marie. I am so grateful for your unwavering support and encouragement.

To everyone listed above, I have learned so much during my tenure as a doctorate student; your continued help and support has made this experience a memorable one. Thank you!

PREFACE

I, Deborah Jehu, was primarily responsible for the design and implementation of all 5 of the papers included in the current dissertation. Specifically, I examined the stability of posture (Study 1), obstacle clearance (Study 2), functional mobility (Study 3) and attention demand (Studies 1 and 2) across 5 testing sessions in older adults. I was responsible for: conception, the ethics proposal, purchasing and building some of the equipment, participant recruitment of 10 older adults, data collection, analysis, several conference presentations, and the preparation of the manuscripts as well as the dissertation.

For the intervention experiments, I examined whether balance and mobility training and/or balance and mobility plus cognitive training would improve functional mobility (Experiment 3), posture (Experiment 4), obstacle clearance (Experiment 5), and attention demand (Experiments 4 and 5) in older adults. I was responsible for: conception, the ethics proposal, purchasing and building some of the equipment, participant recruitment of 49 older adults, data collection, coordinating lab space, training approximately half of the participants one-on-one 3 times per week for 12 weeks during the interventions, overseeing 2 research assistants who trained approximately half of the participants, analysis, several conference presentations, and the preparation of several manuscripts as well as the dissertation.

Assistance with data collection was provided by Dominique Mercier, Natalie Richer, and Nadia Polskaia (Studies 1 and 2). Assistance with motion analysis was provided by Dominique Mercier (Study 2), Lucas Michaud (Experiment 5), and Jessica Grostern (Experiment 5). Dr. Yves Lajoie taught me how to build the switches used on the obstacles in order to trigger the auditory stimuli (Study 2 and Experiment 5). Dr. Nicole Paquet secured internal funding in order to pay for participant parking during the interventions and testing, as well as pay the 2 research

assistants. Drs. Yves Lajoie and Nicole Paquet have given their wisdom and advice in order to improve the design of these studies and experiments. Input and oversight on the design of the studies and experiments were given during my proposal from my thesis committee members, Drs. Martin Bilodeau and Heidi Sveistrup. Drs. Yves Lajoie and Nicole Paquet have edited the dissertation as well as each of the manuscripts, and were involved in the publication process of papers 1-4. Both Drs. Yves Lajoie and Nicole Paquet give their consent to the inclusion of all 5 papers in my dissertation.

The following provides a summary of the published, in review, and to be submitted works included in this dissertation.

Study 1: Published

Jehu, D. A., Paquet, N., Lajoie, Y. (2016). Examining the stability of dual-task posture and reaction time measures in older adults over five sessions. *Aging and Clinical Experimental Research*. 28(6), 1211-1218.

Study 2: In Review

Jehu, D. A., Lajoie, Y., Paquet, N. Improvements in obstacle clearance parameters and reaction time over a series of obstacles revealed after 5 repeated testing sessions in older adults. *Motor Control*. Manuscript ID MC.2016-0067

Experiment 3: Published

Jehu, D. A., Paquet, N., Lajoie, Y. (2016). Balance and mobility training with or without concurrent cognitive training improves the timed up & go (TUG), TUG cognitive and TUG manual in healthy older adults. *Aging Clinical and Experimental Research*. Aug 18. Epub ahead of print.

Experiment 4: Published

Jehu, D. A., Paquet, N., Lajoie, Y. (2017). Balance and mobility training with or without concurrent cognitive training does not improve posture but improves reaction time in healthy older adults. *Gait and Posture*, 52, 227-232.

Experiment 5: Submitted

Jehu, D. A., Paquet, N., Lajoie, Y. Balance and mobility training with or without simultaneous cognitive training results in no changes in obstacle clearance, but reduced attention demand in older adults. *Motor Control*.

LIST OF ABBREVIATIONS

Term	Description
BMT	Balance and mobility training
BMT+C	Balance and mobility plus cognitive training
COM	Center of mass
BOS	Base of support
COP	Center of pressure
ML	Medial-lateral
AP	Anterior-posterior
FA	Feet apart
ST	Semi-tandem
SD	Standard deviation
RT	Reaction time
SRT	Simple reaction time
CRT	Choice reaction time
MMSE	Mini mental state exam
Godin	Godin leisure-time physical activity questionnaire
BOSU	Both sides up ball
Pelvis ML-COM	An estimate of the pelvis center of mass displacement in the medial-lateral direction

LIST OF TABLES

Study 1

Table 1. Significant main effects for Stance; Mean (SD).....54

Table 2. Significant main effects for RT difficulty; Mean (SD).....55

Study 2

Table 1. Mean \pm SD of Obstacle Clearance (mm).....83

Table 2. Effect of RT on Outcome Measures; Mean \pm SD.....84

Table 3. Effect of Session on Outcome Measures (Mean \pm SD).....86

Experiment 3

Table 1. Participant characteristics (Mean \pm SD).....106

Table 2. Numbers counted during the TUGcog (Mean \pm SD) and the number of participants who spilled water during the TUGman.....108

Table 3. Description of movements and activities of balance obstacle course of level 1.....109

Table 4. Average (\pm 1 SD) of the timed-up-and-go (TUG), TUG cognitive (TUGcog), and TUG manual (TUGman) in seconds for the balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and control groups.....114

Table 5. Preliminary study on repeated testing (n=10) (Mean \pm SD).....115

Table 6. Comparison of results between the preliminary study and baseline of the intervention (Mean \pm SD).....116

Experiment 4

Table 1. Participant characteristics (Mean \pm SD).....134

Table 2. Description of movements and activities of level 1 of the balance obstacle course and associated cognitive tasks.....137

Table 3. Postural measures by group and session (Mean \pm SD).....	141
---	-----

Experiment 5

Table 1. Participant characteristics (Mean \pm SD).....	158
--	-----

Table 2. Description of movements and activities of level 1 of the balance obstacle course, associated cognitive tasks, and levels attained following training.....	163
--	-----

Table 3. Mean \pm SD (mm) of the BMT, BMT+C, and Control groups over time.....	169
---	-----

LIST OF FIGURES

Study 1

Figure. 1. Average (± 1 SD) simple reaction time (SRT) and choice reaction time (CRT) over 5 sessions. $*p<0.001$56

Figure. 2. Within-subject standard deviation (± 1 SD) of simple reaction time (SRT) and choice reaction time (CRT) over 5 sessions. $*p<0.001$57

Study 2

Figure. 1. Diagram of 6 obstacles of varying heights with foot-switches triggering auditory stimuli.....78

Figure. 2 A. Mean ($+ 1$ SD) of simple reaction time (SRT) (s); **B.** Mean ($+ 1$ SD) of choice reaction time (CRT) (s); **C.** SD ($+ 1$ SD) of simple reaction time (SRT) (s); **D.** SD ($+ 1$ SD) of choice reaction time (CRT) (s) when walking over 6 obstacles of varying heights over 5 sessions. $*p<0.05$, $\dagger p<0.07$87

Experiment 3

Figure. 1. Flow chart of participant recruitment, adherence and attrition.....104

Experiment 4

Figure. 1. Average ($+ 1$ SD) of simple reaction time (SRT) and choice reaction time (CRT) across feet apart (FA) and semi-tandem (ST) conditions for the balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and control groups at baseline, post-training, and 12-week follow-up. $* p<0.05$; $\dagger p=0.056$142

Experiment 5

Figure 1. Flow chart of participant recruitment, adherence and attrition.....156

Figure 2. Diagram of 6 obstacles of varying heights with foot-switches triggering auditory stimuli.....	159
Figure 3a. Average (+ 1 SD) of simple reaction time (SRT) and choice reaction time (CRT) for the balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and control groups at baseline, post-training, and 12-week follow-up. * $p < 0.05$; 3b. SD (+ 1 SD) of simple reaction time (SRT) and choice reaction time (CRT) for the balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and control groups at baseline, post-training, and 12-week follow-up. * $p < 0.05$; † $p = 0.056$	170

CHAPTER 1: GENERAL INTRODUCTION

Canada's aging population

The percentage of Canadians over the age of 65 has increased primarily due to the post-World War II baby boom, an increase in longevity, as well as subsequent declines in birth rates (Health Canada, 2002). In fact, it is estimated that older adults constitute nearly one-third of the Canadian population (Rawson & Saad, 2010), and the projected number of older adults is estimated to increase by 43% between the years 2000 to 2020 (Anderson & Hussey, 2000). This shift in population will further strain Canada's health care system as older adults have historically had a high demand for health care services (Turcotte & Schellenberg, 2006). Consequently, research which focuses on interventions that enable healthier aging may improve balance and falls-risk.

Impact of falls in older adults on the health care system

Falls can be defined as an event in which a person unintentionally comes to rest on the ground, floor, or other lower level for reasons other than a sudden onset of acute illness or overwhelming external force (KelloggGroup, 1987). The health care costs associated with fall-related injuries are very taxing on the system. An estimated one-third of those aged 65 and older experience one or more falls every year (Gillespie et al., 2012) and almost 50% of older adults suffer a minor injury from a fall with approximately 5% to 25% suffering from a serious injury such as a fracture or a sprain from a fall (Alexander, Rivara, & Wolf, 1992). A fall can be fatal. Approximately 60% of all fatal falls occur in the home, and this is true for general older adult populations as well as high-risk populations (e.g., Parkinson's disease; Bloem, Grimbergen, Cramer, Willemsen, & Zwinderman, 2001; Bloem, Steigns, & Smits-Engelsman, 2003). Although falls have direct physical consequences, other changes in behaviour and lifestyle are

associated with falls (King & Tinetti, 1995). For example, falls have been associated with functional impairment (Kiel, O'Sullivan, Teno, & Mor, 1991; Tinetti & Williams, 1998), activity restriction (Kosorok, Omenn, Diehr, Koepsell, & Patrick, 1992), fear of falling (Howland, Peterson, Levin, Fried, Pordon, & Bak, 1993), premature institutionalization (Dunn, Furner, & Miles, 1993), and mortality (Baker & Harvey, 1985) in older adults.

Older adults encompass a large proportion of the Canadian population and have a historically high demand for health care services; this results in an overall tremendous impact on Canada's health care system (Turcotte & Schellenberg, 2006). In 2004, falls accounted for 50% of the total injuries resulting in hospitalization in Canada (Smartrisk, 2009). Falls also were the leading cause of injury expenditure, with an estimated \$6.2 billion in total costs (Smartrisk, 2009). This emphasizes the importance of research dedicated to fall prevention in older adults in order to decrease the burden on the health care system and improve the quality of life in Canada's aging population. To better understand factors related to fall prevention, the next section describes the role of aging in a number of important measures.

Role of aging on postural sway

Maintaining upright stance involves the proper integration of sensory information from visual, vestibular, proprioceptive, and cutaneous inputs (Massion, 1994). It also relies on the efficiency of postural adjustments across varying task and environmental demands (Horak, 2006). Age-related deteriorations in the sensory systems can lead to alterations in balance, falls, and severe injuries (Tinetti, Speechley, & Ginter, 1988). For example, visual perception often deteriorates with aging, specifically contrast sensitivity and depth perception (Lord, 2006). Age-related degeneration of the semicircular canals and otolith function can occur in the vestibular system (Agrawal et al., 2012). Alterations in position and motion sense (Goble, Coxon,

Wenderoth, Van Impe, & Swinnen, 2009), as well as a decrease in the size and density of cutaneous receptors also occur with advancing age (Shaffer & Harrison, 2007). Additionally, changes in neuromuscular structure and function result in impaired motor performance (Aagaard, Suetta, Caserotti, Magnusson, & Kjaer, 2010), and can compromise the ability to adapt to postural perturbations (Bugnariu, & Sveistrup, 2006). As a result of these age-related sensory, perceptual and neuromuscular declines, modulations to the postural control system have been displayed by an increase in the area of postural sway (Bernard-Demanze, Dumitrescu, Jimeno, Borel, & Lacour, 2009), an increase in the velocity of postural adjustments (Bernard-Demanze et al., 2009), and predictable and less adaptive postural control (Manor et al., 2010). A change in the structure of variability of postural sway has been postulated to be a reorganization of the system to adapt to the imposed constraints (Rhea et al., 2011). Taken together, these age-related changes to the postural control system highlight the importance for interventions targeted at mitigating these deficits.

Role of aging on functional mobility

Age-related changes to body systems are often also accompanied by a deterioration in health and functional capacity. One of the major causes of functional capacity deficits is impaired mobility. The ability to safely ambulate is an essential activity of daily living and important for independent living. Older women in their 70s are at a greater risk for a decline in functional mobility, perhaps due to a greater loss of muscle mass and strength (Nakano, Otonari, Takara, Carmo, & Tanaka, 2014). Additionally, impaired mobility has been correlated with a greater risk for falls in the following year, further deterioration in functional capacity, and greater risk for institutionalization (Boulgarides, McGinty, Willett, & Barnes, 2003). This suggests that

older adults who already present mobility issues may be at a greater risk for succumbing to the adverse effects of aging.

A number of tests have been developed in order to assess overall functional mobility, balance, and risk of falling among older adults. Some examples include: the timed-up & go (TUG) test, Tinetti performance oriented mobility assessment test, berg balance scale test, community balance and mobility scale test, one-legged stance test, physiological profile assessment, and the functional reach test. These tests assess various aspects of functional mobility such as standing balance, stepping ability, reaction time (RT), lower limb strength, dual-tasking, gait variability, gait cadence, and vision (visual acuity, contrast, and field; Brouwer, Musselman, & Culham, 2004). Importantly, low functional mobility scores have been associated with falls (Borowicz, Zasadzka, Gaczkowska, Gawłowska, & Pawlaczyk, 2016); thus, interventions aimed at improving functional mobility and sustained independence are critical for the aging population.

Role of aging on obstacle clearance

Aging has been associated with deteriorations in gait with overlying impacts on obstacle clearance (Chen, Schultz, Ashton-Miller, Giordani, Alexander, & Guire, 1996). Older adults adopt a variety of changes to gait parameters during locomotion. These modulations in gait parameters in older adults have been characterized by slower walking speed (Gill et al., 2001), less overall trunk sway while walking (Gill et al., 2001), decreased stride length (Lajoie, Teasdale, Bard, & Fleury, 1996), increased stride width (Blanke & Hageman, 1989), prolonged double limb support, and increased stride-to-stride variability (Sekiya, Nagasaki, Ito, & Furuna, 1997). Additionally, older adults present slower obstacle crossing speed, smaller toe clearance, and greater heel clearance variability relative to young adults (Harley, Wilkie, & Wann, 2009).

In general, older adults tend to adopt a conservative and cautious obstacle crossing strategy; however increased task demands place older adults at an even greater risk for tripping than young adults (Harley et al., 2009).

Older adults are often succumbed to diminished sensory and perceptual function, an important factor for successful obstacle clearance. In fact, the placement of the lead foot on an obstacle has been postulated to be controlled and modified by visual information, whereas only feed-forward visual information in combination with kinesthetic sensory feedback for the swing foot can be used in order to accomplish successful obstacle negotiation (Patla, 1997). Age-related deteriorations in obstacle crossing influence the crossing strategy employed. Two possible strategies for avoiding a trip during obstacle crossing involve increasing the mean clearance height and decreasing the variability of the minimum foot clearance (Begg et al., 2007). Increasing the mean height is likely associated with a greater metabolic cost, whereas decreasing variability is suggestive of increased control and efficiency (Begg et al., 2007). Conversely, other research has revealed that older adults with a low risk for falls exhibit smaller toe-obstacle clearance and smaller variability than older adults with a high risk for falling (Pan, Hsu, Chang, Renn, & Wu, 2016). Therefore, perhaps a decreased mean clearance coupled with small variability of step clearance may be suggestive of more efficient obstacle crossing. In sum, these findings raise a critical issue for the aging population, and underline the importance of interventions targeted at improving obstacle clearance.

Role of aging on attention demand

Putatively, dual-tasking refers to the performance of two activities simultaneously (Woollacott & Shumway-Cook, 2002). Dual-task paradigms have been used to differentiate and expose the role of cognitive function on motor control (Woollacott & Shumway-Cook, 2002).

For instance, older adults who are forced to stop walking when talking have been exposed to be more at risk for a fall (Hyndman & Ashburn, 2004). Deficits in stimulus encoding (i.e., slower simple RT), central processing (i.e., slower complex RT), and response initiation (i.e., slower voluntary movement times) have also been prevalent in the older population (Stelmach & Worringham, 1985). Dual-task performance primarily depends on the capacity to divide attention between the balance task and the second task (Verhaeghen & Cerella, 2002). Moreover, the majority of falls in balance-impaired older adults occur when they are walking while performing a second task, not just simply walking (Tideiksaar, 1996). To this end, researchers have hypothesized that falls may not be a result of balance deficits in isolation, but the inability to effectively allocate attention to balance in dual-task situations (Lajoie et al., 1996; Shumway-Cook, Brauer, & Woollacott, 2000). Previous work has outlined several assumptions of the dual-task model. That is, the capacity for information-processing is limited; the fact that completing a task demands a portion of this capacity; and performance on either or both tasks will deteriorate if concurrently performing the two tasks exceeds capacity (Kahneman, 1973). The capacity theory and the bottleneck theory are two theoretical frameworks that have been proposed to illuminate differences in dual-task performance (Fraizer & Mitra, 2008).

The capacity theory postulates that dual-task interference arises from sharing limited attentional resources (Fraizer & Mitra, 2008). It stipulates that if attention demands exceed processing capacity, then performance on one or both of the tasks will be curtailed (Kahneman, 1973; Remaud, Boyas, Lajoie, & Bilodeau, 2013). Some theorists argue that attentional resources are drawn from a single pool of resources (Kahneman, 1973), while others assume attention is drawn from multiple resource pools (Huang & Mercer, 2001; Pashler, 1994; Remaud et al., 2013). According to multiple-resource theories, dual-task interference only occurs when

two tasks compete for the same input or output processes (Huang & Mercer, 2001; Weeks, Forget, Mouchnino, Gravel & Bourbonnais, 2003). Therefore, several tasks can be performed concurrently as long as the resource capacity limits are not exceeded.

Alternatively, the bottleneck theory surmises that parallel processing may be difficult when the same cognitive processing operations are utilized (Pashler, 1994). In turn, a bottleneck effect occurs and the tasks must be completed sequentially (Pashler, 1994). This model stipulates that during a competition for attentional resources, the individual selects an appropriate task-prioritization strategy in order to minimize danger and maximize pleasure (Yogev-Seligmann, Hausdorff, & Giladi, 2012). That is, the central nervous system is thought to temporarily delay the performance of the non-prioritized task, corresponding to associated performance decrements (Fraizer & Mitra, 2008). Previous work has suggested that older adults prioritize posture first and the secondary task second (Shumway-Cook, Gruber, Baldwin, & Liao, 1997). Therefore, inappropriate attention allocation may result in balance disturbances and/or falls. Given the age-related deficits in attention demand, interventions targeting the improvement of divided attention are particularly important for the older adult population.

Effectiveness of dual-task interventions on balance and cognition in older adults

Research is mixed on the gold standard for the design of interventions. It is known that the following factors are important for designing an effective intervention: increasing the intensity of a task to ensure that there is adequate load, ensuring above threshold frequency, performing the appropriate type of exercise for the target population, and including an adequate duration of the training program (Oberg, 2007). In order to decrease the risk for falls in older adults, Sherrington et al. (2008) recommended that training programs be moderately to highly challenging, of sufficient dose including training at least 2 hours per week summing to over 50

hours in total, be ongoing for a lasting fall prevention effect, be targeted to older adults at risk and not at risk for falls, be performed at home or in a group, not be singularly comprised of a walking program, offer the option of strength training as it may provide further benefits, and provide referrals to other risk factors for falls such as cataract surgery. Another systematic review suggests that, in general, the most effective training programs that improved balance were challenging and ran 3 times per week for 3 months (Howe et al., 2012). However, these authors also suggest that despite the large body of literature on training programs in older adults, the improvement in balance is conflicting due to the multiple outcome measures used (Howe et al., 2012). In addition, at the time of this review, the majority of the experiments included were general single-task training programs, and not dual-task interventions (Howe et al., 2012). The most recent guidelines suggest that the balance training is: 1) highly challenging such that the base of support is reduced, the center of mass is moving, and the use of support implements is limited; 2) performed at least 3 times per week; and 3) ongoing, otherwise improvements in outcome measures will be lost (Sherrington et al., 2016). Taking the aforementioned recommendations into consideration, investigating the effects of dual-task training programs in older adults may be especially important due to their applicability to daily life.

Dual-task training has received a great amount of attention in the last 10 years. Dual-task training has been suggested to be successful as it may promote the automatization of tasks, and free processing capacity in older adults (Pichierri, Wolf, Murer, & de Bruin, 2011). As a consequence, more attention is available to process external information and react faster to sudden disturbances (Pichierri et al., 2011). Dual-task training appears to be necessary in order to improve dual-tasking, as single-task interventions have shown no transfer effects to dual-task performance (Agmon, Belza, Nguyen, Logsdon, & Kelly, 2014). Other work suggests that both

single and dual-task interventions were successful at improving dual-task walking, while only dual-task balance training was effective at improving dual-task postural control (Wollesen & Voelcker, 2013). Researchers are now suggesting that dual-tasking should be incorporated into fall prevention programs for older adults (Pichierri et al., 2011). The following discourse reviews the effectiveness and advancements of individual dual-task interventions to date.

Dual- compared to single-task training benefits in older adults

One experiment aimed to determine whether the addition of cognitive training to a general exercise program would elicit further improvements in executive functioning and gait parameters in older adults (Falbo, Condello, Capranica, Forte & Pesce, 2016). All participants trained for one hour, twice weekly for 12 weeks on coordination, balance, strengthening, and agility exercises. The dual-task training group also concurrently performed executive functioning tasks involving inhibition (i.e., the ability to inhibit automated processes), working memory (i.e., the ability to hold, process, and manipulate information), and set-shifting (i.e., the ability to modulate stimulus-response associations when performing continuous tasks). Results revealed that both single- and dual-task training groups improved in gait speed and stride time variability; however, only the dual-task training group elicited improvements in inhibition processes following training. These findings suggest that both single- and dual-task interventions may equally improve in gait parameters, but dual-task interventions offer further improvements in executive functioning. However, the authors report that only the executive functioning variables elicited adequate power; therefore, future work is necessary in order to determine whether dual-task training can also provoke further improvements in gait variables.

van het Reve and de Bruin (2014) explored the influence of strength and balance training compared to strength and balance plus computerized cognitive training in 182 frail older adults.

All participants trained twice per week for 40 minutes for 12 weeks. The strength and balance plus cognitive training group also completed computerized dual-task cognitive exercises 3 times per week for 10 minutes. Both training groups improved in physical and cognitive performance, while the strength and balance plus cognitive training group showed additional benefits to dual-task costs of walking and divided attention. These results highlight that the addition of cognitive training to a balance training regime can elicit further benefits to physical functioning; however, it is unknown whether completing strength and balance training simultaneously with cognitive training (i.e., dual- compared to separated single-task training) would have provoked further improvements in outcome measures.

Other research has examined the impact of treadmill training with concurrent cognitive training compared to an inactive control group in older adults with multiple falls (Dorfman et al., 2014). Participants walked on a treadmill for 15-45 min 3 times per week for 6 weeks while completing concurrent cognitive tasks. Results revealed significant improvements in the Berg Balance Scale, the Dynamic Gait Index, single- and dual-task gait speed, and cognitive performance relative to the control group. These findings support the notion that dual-task training is feasible in improving functional mobility and cognition in older adults with a history of falls. However, this study did not include a control group; therefore, it is unknown whether the addition of cognitive training to treadmill training would provoke further improvements in outcome measures relative to treadmill training itself.

One recent dual-task training experiment examined the influence of a 26-week randomized controlled trial comparing dual- and single-task interventions in active older adults (Gregory et al., 2016). Participants attended a 60 to 75-minute group exercise class incorporating aerobic, strength, balance and flexibility 2-3 times per week. Both groups also performed 15

minutes of square stepping exercises 2-3 times per week. In addition to these exercises, the dual-task exercise group was asked to respond to cognitively challenging questions during the square stepping exercises. Results demonstrated significant improvements in gait parameters in the dual-task training group relative to the single-task training group after the intervention. Specifically, significantly faster dual-task gait velocity, greater dual-task step length, and reduced dual-task stride time variability were shown in the group that received dual-task training. This work adds to the literature that dual-task training can promote mobility in the older population, but these findings should be confirmed with a larger sample size.

Another experiment aimed to compare the impact of balance training, multisensory balance training, and balance plus cognitive training in older adults (Nematollahi, Kamali, Ghanbari, Etminan, & Sobhani, 2016). Participants trained 3 times per week for an hour for 4 weeks. Significant improvements in static and dynamic balance emerged, however no changes in dual-task performance were observed between groups. This lack of change may be a result of the outcome measures only being assessed in a single-task context. Similarly, Berryman et al. (2014) also explored 3 different single-task interventions in older adults. All participants trained 2 times per week for 1 hour for 8 weeks. The interventions included lower body strength and aerobic training, upper body strength and aerobic training, and gross motor activities. Results revealed improved VO_2 max in both aerobic training groups, no functional mobility improvements, and similar improvements in cognition between groups. Perhaps no improvements in dual-tasking were shown across training groups as participants did not specifically train dual-tasking. This emphasizes the notion that dual-tasking should both be trained and tested in order to determine whether significant differences between training groups exist.

The concept that both cognitive and motor dual-tasks should be trained and tested is in congruence with similar previous literature. For example, previous work has examined two groups of older adults who completed a 12-week, twice per week lower limb resistive training and balance training, incorporating standing on one leg, tandem walking, and stepping over objects (de Bruin, van Het Reve, & Murer, 2013). One of the groups also received a 10-week, 3-5 times per week for 10 minutes, computerized cognitive-cognitive dual-task intervention that commenced in the third week of the balance training. The testing protocol consisted of measuring walking while performing either a cognitive or motor dual-task. Results disclosed faster foot RTs in the dual-task training group; however, no other definitive improvements were presented. One critique for this experiment could be that the comparison group received 12 weeks of balance training while the experimental group received the same training with the addition of only 300 minutes of cognitive training. Given that only 7 and 6 older adults participated in the control and experimental groups respectively, further improvements in dual-tasking may have occurred with a greater sample size.

In parallel, other work has examined the effects of a once weekly, 45-minute, 4-week dual-task training program among older adults living in a retirement home (Plummer-D'Amato, et al., 2012). The single-task training group participated in a weekly single-task training program that included walking and performing balance activities while negotiating an obstacle course. The dual-task training group completed dual-task training including cognitive, balance, and walking activities while manoeuvring through an obstacle course. Each group also participated in the same seated and standing exercises two additional days of the week. Results showed that both groups increased gait speed, and revealed no differences on any of the cognitive dual-task measures. It is possible that the dual-task training group did not show improvements in dual-task

performance, as only a total of 3 hours of dual-task training was completed for each participant. This highlights the importance for longer intervention periods in order to elicit improvements in dual-task performance.

Another experiment has explored whether separate physical and cognitive training exercises could improve dual-tasking compared to stretching and toning exercises in older adults (Desjardins-Crépeau et al., 2016). Participants in the training group completed aerobic and muscular endurance exercises twice per week, as well as computerized dual-task cognitive exercises once per week for 1 hour. Participants in the stretching and toning group trained 2 times per week for 1 hour and completed an introductory computer course. Results revealed that both training groups improved functional mobility, but only the physical activity group who completed dual-task cognitive training exhibited transfer effects to executive functioning. However, it is unknown whether completing physical and cognitive training concurrently (i.e., dual- compared to separated single-task training) would have provoked further improvements in outcome measures.

Previous research compared the influence of 5 minutes of dual-task walking exercises compared to 5 minutes of single-task walking once per week for 24 weeks (Uemura et al., 2012). All participants also performed seated exercises for 30 minutes once per week for 24 weeks. Authors examined gait initiation and steady state gait under single and dual-task conditions. Both groups improved on steady state gait under the dual-task condition; however, only the group who trained dual-tasking improved RT and backward center of pressure displacement during gait initiation. These results reveal that as little as 2 hours of dual-task training within a 24-week period can promote further improvements in dual-tasking. Nevertheless, interventions of short

durations do not provoke consistent improvements in balance, which suggests that longer training periods may be necessary (Sherrington et al., 2008).

Another experiment aimed to determine whether general exercise training with the addition of dual-task exergames would improve voluntary stepping in frail older adults (Pichierri, Coppe, Lorenzetti, Murer, & de Bruin, 2012). Participants in the intervention group trained twice per week for 1 hour for 12 weeks, incorporating aerobic, resistance, balance, dual-task exergames, while the control group did not complete training. Significant improvements in single- and dual-task forward and backward step initiation occurred in the intervention group relative to the control group. This adds to the literature that dual-task training is sufficient in improving step execution under single and dual-task conditions in older adults. Due to the multifactorial nature of this study, it is unknown whether the single-task resistance training, single-task balance exercises, or dual-task dance video gaming in isolation or in combination provoked the improvements in outcome measures.

Limited research has examined the differences in training-related brain adaptations following dual- and single-task training. Recent research compared a dual-task exergame intervention and a single-task balance training intervention in older adults (Schättin, Arner, Gennaro, & de Bruin, 2016). All participants trained 3 times per week for 30 minutes for 8 weeks, and were tested at baseline and after the interventions on prefrontal brain activity, executive functioning tasks (i.e., working memory, divided attention, go-/no-go, and set-shifting), and gait parameters. Results revealed less prefrontal brain activity in the dual-task exergame group compared to the single-task balance training group, which may suggest that dual-task exergaming increases the connections between brain areas, thereby facilitating a better control of neural networks (Ho et al., 2012). In addition, the dual-task exergame group

significantly improved in all four executive functioning tasks, while the single-task balance group only improved in set-shifting following the intervention. Lastly, the dual-task exergame group showed further improvements in dual-task gait parameters compared to the single-task balance training group. Improvements in cognitive functioning, brain activation, and functional mobility following concurrent cognitive and exercise training are also in line with previous research (Law, Barnett, Yau, & Gray, 2014; Nishiguchi et al., 2015). Thus, these experiments add to the dual-task training literature that improved neural efficiency may be a function of dual-task training; this therefore emphasizes the importance of dual-task training prescription among older adults. However, further research is necessary to determine the optimal frequency, intensity, type and duration of the interventions in order to provoke the maximum improvements in balance while decreasing the risk for falls.

Effects of dual-task training on transfer effects in older adults

The transfer of skills can be defined as the generalization of learning from trained to untrained tasks (Lussier, Gagnon, & Bherer, 2012). Previous research has examined whether single-task training transfers to dual-task postural control and showed negative results (Hall, Miszoko, & Wolf, 2009; Agmon, Kelly, Logsdon, Nguyen, & Belza, 2012). Moreover, some dual-task training experiments in older adults have reported significant transfer effects (Kramer et al., 1995; Bherer et al., 2005, 2008; Salminen, Frensch, Strobach, Schubert, 2016; Yamada et al., 2011), whereas others have not (Dahlin et al., 2008; Green & Bavelier, 2008; Owen et al., 2010; Silsupadol et al., 2009; Silsupadol, Siu, Shumway-Cook, & Woollacott, 2006). In the research reporting improved transfer effects, it is unclear whether it was a result of reduced task-set cost (i.e., the improved ability to maintain several response alternatives) or of improved response coordination (i.e., improved dual-task cost). Some transfer effects seem larger if the

trained and untrained tasks share a common input modality (e.g., both tasks involve visual input) and a motor response modality (e.g., both task require motor responses). Lussier et al. (2012) aimed to assess the extent to which modality transfer effects can be expected after dual-task training in older and younger adults. More specifically, they examined whether computerized cognitive-cognitive dual-task training resulted in a transfer of learning when the stimulus modality, response modality, and stimulus and modality were altered in a dual-task context in both young and older adults. Participants were trained over 5 sessions for one hour on discrimination-type tasks. Results revealed improved dual-task cost only in conditions that involved new stimuli or response modalities, but not both, in the young and older trained groups relative to the age-matched control groups. Training did not provoke a reduced task-set cost in the transfer conditions, which suggests some limitations in transfer effects. Altogether, the cumulative evidence points towards the notion that dual-task training may promote transfer effects due to cognitive plasticity in older adults.

In contrast, other research has shown limited transfer effects. Granacher and colleagues (2010) examined the effects of a 6-week, 3 times per week balance training program in older adults. This program included a warm-up and cool-down on an aerobic machine, and progressive postural stabilization tasks with the addition of manual dual-tasks. Testing involved walking 10 m while performing a cognitive or manual task. Results showed that the training group reduced the stride time variability compared to the control group; however, no differences were disclosed in the other gait parameters. The training group also exhibited significantly improved manual but not cognitive task performance. It is possible that improvements in cognitive dual-tasks were not demonstrated as they were not trained, but were tested. Similarly, other work has examined transfer effects following single-task motor training, single-task cognitive training, dual-task

motor-cognitive training, and dual-task cognitive-cognitive training in older adults (Wongcharoen, Sungkarat, Munkhetvit, Lugade, & Silsupadol, 2016). Participants trained at home, 3 times per week for an hour, for 4 weeks. As hypothesized, the motor-cognitive training was more effective than the single-task motor training to improve dual-task balance performance. However, improved dual-task processing skills during training were not transferred to the novel dual task. Therefore, it seems that training should be specific enough to show improvements in the tasks that are trained but broad enough to produce a transfer to other skills. It may be important to both train and test motor and cognitive tasks during balance training to show improvements in these tasks.

An area of growing interest is the exploration of whether fixed compared to variable-priority dual-task training promotes a greater transfer of skills. A variable-priority instructional set involves switching attention focus such that the majority of attention is placed on one task compared to the other, while fixed-priority training involves an equal distribution of attention focus between tasks (Silsupadol et al., 2009). Researchers examined single-task, dual-task with fixed-priority training, and dual-task with variable-priority training three times per week for four weeks in older adults. Single-task training included balance tasks such as tandem standing, transferring from one chair to another, and walking with a reduced base of support. Dual-task fixed-priority training consisted of performing the same set of balance tasks as single-task training in addition to simultaneously performing cognitive tasks, while giving both tasks equal-priority. The dual-task variable-priority group participated in the same activities as the fixed-priority dual-task group, but were instructed to focus on the postural task for half of the training session and the cognitive task for the other half. Results revealed that the variable-priority dual-task group exhibited improved balance and cognitive performance under dual-task conditions

compared to the other groups. This suggests that variable-priority training promotes increased automatization of skills (i.e., reducing dual-task interference). However, dual-task training did not transfer to novel dual-task conditions such as obstacle crossing while responding to an auditory stimulus. These improvements also did not reveal improvements in gait parameters such as stride length in any of the groups. The lack of improvement may be a function of the dissimilarity between the skills practiced and practice environment compared to the tests and the testing environment.

Building upon the notion that variable-priority training is more beneficial than fixed-priority, Lussier, Bugajska, and Bherer (2016) aimed to determine whether greater transfer effects would occur with variable-priority computerized cognitive-cognitive dual-task training in older adults. Participants completed 5 1-hour training sessions. Results revealed that the variable-priority training group exhibited superior performance on a near and far computerized transfer task. In contrast, other work examining 6 1-hour sessions over 2 weeks of computerized single-task, fixed-priority, and variable-priority training in older adults showed no differences in the transfer tasks between the fixed and variable-priority tasks (Bier, de Boysson, & Belleville, 2014). Perhaps future research should be conducted in order to determine if there is an ideal attention priority during testing and training to optimize learning in older adults.

Contrarily, significant improvements in balance performance under narrow walking and narrow walking while performing the verbal fluency task were observed following a computerized single cognitive task training regime; however, no improvements were observed in the variable-priority computerized cognitive-cognitive dual-task training program in older adults (Wollesen, Voelcker-Rehage, Willer, Zech, & Mattes, 2015). Perhaps the increased processing demand of variable-priority instructions was excessive and may have prevented participants from

learning the tasks. It is therefore important that attention demand is sufficiently elevated during training without overloading the system.

Effects of cognitive-cognitive dual-task training interventions in older adults

Some research has established improvements in cognition as well as gross motor skills following cognitive-cognitive dual-task training in as little as five training sessions (Li et al., 2010). Participants completed a variety of two-choice visual discrimination tasks with feedback on a computer. The following outcome measures were used while simultaneously completing an n-back test: standing on one leg with eyes open and closed, standing on two legs, moving from sitting to standing positions, and a 40-foot walk test. Some of the improvements in the training group included faster RT, reduced sway during one-legged and two-legged stance, and faster walking speed during the 40-foot walk. There were no improvements in the control group. These findings have also been corroborated by other cognitive-cognitive dual-task training experiments that have shown transfer effects to gross motor skills (Smith-Ray, Makowski-Woidan, & Hughes, 2014; Wongcharoen et al., 2016; Mozolic, Long, Morgan, Rawley-Payne, & Laurienti, 2011; Verghese, Mahoney, Ambrose, Wang, & Holtzer, 2010). These experiments highlight that seated cognitive training that emphasizes the ability to divide or rapidly shift attention has the potential to improve dual-tasking in older adults.

Summary of dual-task training literature in older adults

Despite the majority of the research suggesting that dual-task training improves dual-task performance (e.g., Law et al., 2014; Nishiguchi et al., 2015; Schättin et al., 2016), some research has shown no or limited improvements (Hamacher, Hamacher, Rehfeld, & Scheega, 2016; van Diest et al., 2016; Plummer D'Amato et al., 2012). Howe and colleagues (2012) suggest that it is difficult to draw accurate conclusions of the impact of exercise interventions, as a variety of

outcome measures have been used. Perhaps the lack of improvements in these experiments may stem from unsupervised home-based training (van Diest et al., 2016), or including only 3 hours of dual-task training (Plummer D'Amato et al., 2012). The findings stress the importance of adequate cognitive loading, supervised training, and designing a program of adequate duration.

Exercise training has been documented to be the most important corrective factor to decrease the risk for falls in older adults (Howe et al., 2012), which suggests that incorporating dual-tasking into a progressive exercise training is paramount. Previous literature has mainly incorporated cognitive dual-tasks into physical training regimes. However, limited research has explored the influence of balance training paired with concurrent motor tasks on dual-task performance in older adults. Additionally, previous research has suggested that training motor and cognitive tasks are necessary to improve these tasks (Granacher, et al., 2010; Wongcharoen, et al., 2016); however, there remains a gap in the literature as to whether balance training paired with a concurrent motor and cognitive task would prove to elicit even more benefits in dual-tasking compared to balance training paired with concurrent motor tasks. While other physiological, psychological or functional changes may occur as suggested by the literature, the focus of this thesis is to examine the influence of dual-task training on dual-task performance in older adults.

Maintenance of dual-task training improvements at the follow-up

In addition to designing an effective dual-task intervention, it is also important to understand whether dual-task training-related improvements persist over time. A previous systematic review critiques balance training interventions for not including a follow-up after training (Howe et al., 2012). Of the dual-task training experiments that have included a follow-up, some research has retained improvements in cognitive performance at a 2-week (Bisson,

Contant, Sveistrup, & Lajoie, 2007), 1-month (Bisson et al., 2007), 1-year (Eggenberger et al., 2015), and 5-year follow-up (Oswald et al., 2006). Similarly, other experiments have shown some degree of retention in motor performance for follow-ups ranging from 2-6 months (Silsupadol et al., 2009; Silsupadol et al., 2006). Preserved gait parameters at a 6-month follow-up (Gregory et al., 2016), and sustained functional mobility at a 3-month follow-up (Carvalho, Marques, & Mota, 2009; Lacroix et al., 2016) have also been evidenced following dual-task interventions. Nevertheless, other research has shown no retention of improvements in balance, gait or cognition at the 1 month follow-up (Dorfman et al., 2014), or postural control at the 6- or 12-month follow-up (Halvarsson, Oddsson, Franzén, & Ståhle, 2016). Perhaps improvements were not sustained over time due to a short training period (e.g., 6 weeks; Dorfman et al., 2014), or perhaps the follow-up period was too long after the intervention (e.g., 6 months and 1 year; Halvarsson et al., 2016). Overall, this literature suggests that dual-task training may be effective at sustaining dual-task improvements over time, provided that the dual-task training protocol is adequately designed and the follow-up is not too long after the intervention. Due to the dearth of dual-task interventions including a follow-up, this thesis examined the influence of persistence of improvements over time.

Caution when interpreting significance from balance training programs

It is important that researchers are cautious about repeated exposure to a testing protocol as improvements in the outcome measures may be a function of the serial administration of the testing protocol as opposed to the intervention itself. For example, improvements on the Romberg test have been shown across 5 testing sessions, and improved posture has been elicited after 10 sessions of standing on firm and foam surfaces (Nordahl, Aasen, Dyrkorn, Eidsvik, & Molvaer, 2000). Indeed, improvements in outcome measures have been heightened when the

testing interval was shortened (Nordahl et al., 2000). These findings underline the potential for committing type 1 error when interpreting findings from an intervention.

Unlike posture, the repeatability of functional mobility measures has not been measured. Although excellent test-retest reliability (ICC=0.960) in the TUG has been evidenced across 5 consecutive days, research has failed to statistically compare whether these sessions were significantly different from each other (Smith, Walsh, Doyle, Greene, & Blake, 2016). Clinically relevant improvements in functional mobility have been reported to be -0.8 ± 0.5 s for the TUG in community-dwelling older adults (Thiebaud, Funk, & Abe, 2014). In turn, significantly faster TUG scores were indicated between the first and fifth testing sessions (Smith et al., 2016). These differences suggest that significant improvements may be shown across repeated administration.

Similarly, no previous research has examined the repeatability of obstacle clearance testing protocols. High two-week test-retest reliability of gait variability has been reported, with intra-class correlation coefficient values for speed, cadence, step duration, and step length ranging from 0.84–0.93 (van Iersel, Benraad, & Olde Rikkert, 2007). Future research should explore whether improvements in dual-task obstacle clearance occur following repeated administration of the testing protocol.

Several researchers have raised queries on the impact of repeated administration of cognitive tasks. Some research has exposed significant improvements in computerized cognitive-motor testing in young and older adults only within the first two testing sessions, with no further improvements shown across subsequent testing sessions (Collie, Maruff, Darby, & McStephen 2003; Falleti, Maruff, Collie, & Darby, 2006). In contrast, visual and auditory RT training prompted steady improvements, without reaching a plateau in performance after 8 (Stobach, Frensch, Hermann, & Schubert, 2012a) and 21 sessions (Stobach, Frensch, Hermann, &

Schubert, 2012b) in older adults. Perhaps the level of difficulty of the cognitive tasks may influence the timing of performance plateaus. This compilation of literature suggests that researchers specializing in interventions should take precaution when interpreting significance following training programs. For this reason, this thesis also compared the repeated exposure to a dual-task testing protocol incorporating posture, functional mobility, obstacle clearance, and attention demand.

CHAPTER 2: RATIONALE, PURPOSE, RESEARCH QUESTIONS & HYPOTHESES

Rationale

Falls and their consequences remain an important health care issue for older adults. Approximately one-third of older adults suffer at least one fall each year (Gillespie et al., 2012). The consequences of these falls can range from serious injury, such as a fracture (Tinetti et al., 1988), to the development of an anxiety or fear related to falling (Tinetti, Mendes de Leon, Doucette, & Baker, 1994). Furthermore, a fall can generate substantial changes in behaviour including alterations in the control of balance, loss of muscle strength, and daily activity curtailment (Tinetti et al., 1994). These changes in behaviour can lead to a negative cycle that results in more falls that further impacts these behaviours, eventually leading to a reduced quality of life, hospitalization, and a loss of independence (Tinetti et al., 1994).

One important factor that may elevate fall risk is a change in balance control strategy. In particular, age-related deteriorations in dual-tasking during walking have been well-documented (Beauchet et al., 2005; Brown, Shumway-Cook, & Woollacott, 1999). That is, older adults tend to show reduced attention capacity to perform more than one task at the same time which results in reduced performance on one or more of these tasks compared to young adults (McCulloch, Mercer, Giuliani, & Marshall, 2009). As a result of age-related degeneration in the brain, a decline in cognitive and motor performance has been shown to have subsequent impacts on activities of daily living (Schättin et al., 2016). In fact, improper attention allocation and a decline in the ability to dual-task have been related to more falls in older adults (Makizako et al., 2010).

In the last 10 years, dual-task interventions have increased in popularity as they have shown significant improvements in cognition, functional mobility, balance, and gait parameters

(e.g., Law et al., 2014; Nishiguchi et al., 2015; Schättin et al., 2016). Interventions involving dual-tasking have been suggested to prompt further improvements in outcome measures compared to single-task training (e.g., Schättin et al., 2016). However, the literature is undecided on the optimal dual-task training program for older adults. The influence of concurrently performing a motor-task during balance training on dual-tasking is not well understood. Additionally, the impact of balance training with concurrent motor- and cognitive-tasks on dual-tasking has not been previously studied. Due to the scarcity of interventions including a follow-up, further research is necessary in order to determine whether dual-task training-related improvements persist over time in older adults. Moreover, the repeated administration of dual-task testing protocols has been understudied. It is therefore important to explore whether dual-task training-related improvements are indeed a function of training, or whether they stem from repeated exposure to the testing protocol.

Purpose

The overarching purpose of this thesis was to investigate the effects of balance and mobility training (BMT) and balance and mobility plus cognitive training (BMT+C) on dual-task postural sway, dual-task obstacle clearance, dual-task functional mobility, and attention demand in older adults.

Research questions and hypotheses

Research question 1

Does the serial administration of a dual-task testing protocol once per week for 5 weeks provoke improvements in dual-task postural sway (Study 1), dual-task obstacle clearance (Study 2), dual-task functional mobility (Study 3), and attention demand (Studies 1 and 2) in older adults?

Hypotheses for research question 1

It was hypothesized that no improvements in postural sway (Diamentopoulos, Clifford, & Birchall, 2003) or functional mobility (Pichierri, Murer, & de Bruin, 2012) would emerge. Although no previous work has examined the repeatability of a dual-task obstacle clearance protocol, it was expected that obstacle clearance parameters would improve over the 5 testing sessions as practicing difficult tasks may provoke learning effects. Lastly, it was thought that attention demand, as measured by (RT), during the postural way and obstacle clearance protocols would improve after repeated exposure (Collie et al. 2003).

Research question 2

Does a 12-week BMT or BMT+C intervention improve dual-task functional mobility (Experiment 3), dual-task postural sway (Experiment 4), dual-task obstacle clearance (Experiment 5), and attention demand (Studies 4 and 5) in older adults?

Hypotheses for research question 2

It was hypothesized that improvements would be exposed in functional mobility (Thiebaud et al., 2014), postural sway (Wolf, Barnhart, Ellison, & Coogler, 1997), obstacle clearance parameters (Lim & Yoon, 2014a), and attention demand (Li et al., 2010) following training, while no improvements were expected for the control group.

Research question 3

Does the added concurrent cognitive training that the BMT+C group performed elicit further improvements in dual-task functional mobility (Experiment 3), dual-task postural sway (Experiment 4), dual-task obstacle clearance (Experiment 5), and attention demand (Experiments 4 and 5) relative to the BMT group?

Hypotheses for research question 3

It was expected that the BMT+C group would evoke further improvements in dual-task functional mobility, dual-task postural sway, dual-task obstacle clearance parameters, and attention demand compared to the BMT group, as the addition of divided attention training to balance training has shown improvements in gross motor skills as well as divided attention (e.g., Li et al., 2010).

Research question 4

Are possible improvements in dual-task functional mobility (Experiment 3), dual-task postural sway (Experiment 4), dual-task obstacle clearance (Experiment 5), and attention demand (Experiments 4 and 5) from a 12-week BMT or BMT+C intervention sustained at the 12-week follow-up relative to the control group?

Hypotheses for research question 4

Consistent with previous research, it was speculated that the training groups would maintain improvements in functional mobility (Lacroix et al., 2016), obstacle clearance parameters (Lim & Yoon, 2014b), and attention demand (Best, Chiu, Liang Hsu, Nagamatsu, & Liu-Ambrose, 2015; Marusic et al., 2016) at the follow-up relative to the control group. Conversely, it was expected that improvements in postural sway would not be maintained at the follow-up, as previous research has shown that the time to complete the one-legged stance returned to baseline values at the follow-up (Halvarsson et al., 2016).

References

- Aagaard, P., Suetta, C., Caserotti, P., Magnusson, S.P., & Kjaer, M. (2010). Role of the nervous system in sarcopenia and muscle atrophy with aging: strength training as a countermeasure. *Scand J Med Sci Sports*, 20(1), 49-64.
- Agmon, M., Kelly, V.E., Logsdon, R.G., Nguyen, H., & Belza, B. (2012). The effect of enhanced fitness (EF) training on dual-task walking in older adults. *J Appl Gerontol*, 34(3), 128-142.
- Agmon, M., Belza, B., Nguyen, H.Q., Logsdon, R.G., & Kelly, V.E. (2014). A systematic review of interventions conducted in clinical or community settings to improve dual-task postural control in older adults. *Clin Interv Aging*, 25,9,477-492.
- Agrawal, Y., Zuniga, M.G., Davalos-Bichara, M., Schubert, M.C., Walston, J.D., Hughes J., Beauchet, O., Dubost, V., Herrmann, F., Rabilloud, M., Gonthier, R., & Kressig, R.W. (2005). Relationship between dual-task related gait changes and intrinsic risk factors for falls among transitional frail older adults. *Aging Clin Exp Res*, 17(4), 270-275.
- Alexander, B.H., Rivara, F.P., & Wolf, M.E. (1992). The cost and frequency of hospitalization for fall-related injuries in older adults. *Am J Public Health*, 82(7), 1020-1023.
- Anderson, G.F. & Hussey, P.S. (2000). Population aging: A comparison among industrialized countries. *Health Aff (Millwood)*, 19(3), 191-203.
- Baker, S.P., & Harvey, A.H. (1985). Fall injuries in the elderly. *Clin Geriatr Med*, 1(3), 501-512.
- Beauchet, O., Dubost, V., Gonthier, R., & Kressig, R.W. (2005). Dual-task-related gait changes in transitionally frail older adults: the type of the walking-associated cognitive task matters. *Gerontology*, 51(1), 48-52.

- Begg, R.K., Best, R., Dell’Oro, L., & Taylor, S. (2007). Minimum foot clearance during walking: strategies for the minimisation of trip-related falls. *Gait Posture*, 25, 191-198.
- Bernard-Demanze, L., Dumitrescu, M., Jimeno, P., Borel, L., & Lacour, M. (2009). Age-related changes in posture control are differentially affected by postural and cognitive task complexity. *Curr Aging Sci*, 2(2), 139-149.
- Berryman, N., Bherer, L., Nadeau, S., Lauzière, S., Lehr, L., Bobeuf, F., Lussier, M., Kergoat, M.J., Vu, T.T., & Bosquet, L. (2014). Multiple roads lead to Rome: combined high-intensity aerobic and strength training vs. gross motor activities leads to equivalent improvement in executive functions in a cohort of healthy older adults. *Age Dordr*, 36(5), 9710.
- Best, J.R., Chiu, B.K., Liang Hsu, C., Nagamatsu, L.S., Liu-Ambrose, T. (2015). Long-term effects of resistance exercise training on cognition and brain volume in older women: Results from a randomized controlled trial. *J Int Neuropsychol Soc*, 21(10), 745-756.
- Bherer, L., Kramer, A.F., Peterson, M. S., Colcombe, S., Erickson, K., and Becic, E. (2008). Transfer effects in task-set cost and dual-task cost after dual-task training in older and younger adults: Further evidence for cognitive plasticity in attentional control in late adulthood. *Exp Aging Res*, 34, 188–219.
- Bherer, L., Kramer, A.F., Peterson, M.S., Colcombe, S., Erickson, K., and Becic, E. (2005). Training effects on dual-task performance: are there age-related differences in plasticity of attentional control? *Psychol Aging*, 20, 695–709.
- Bier, B., de Boysson, C., & Belleville, S. (2014). Identifying training modalities to improve multitasking in older adults. *Age Dordr*, 36(4), 9688.

- Bisson, E., Contant, B., Sveistrup, H., Lajoie, Y. (2007). Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. *Cyberpsychol Behav*, 10(1), 16–23.
- Blanke, D.J. & Hageman, P.A. (1989). Comparison of gait of young men and elderly men. *Phys Ther*, 69(2), 144-148.
- Bloem, B.R., Grimbergen, Y.A., Cramer, M., Willemsen, M., Zwinderman, A.H. (2001). Prospective assessment of falls in Parkinson's disease. *J Neurol*, 248(11), 950-958.
- Bloem, B.R., Steijns, J.A., & Smits-Engelsman, B.C. (2003). An update on falls. *Curr Opin Neurol*, 16(1), 15-26.
- Borowicz, A., Zasadzka, E., Gaczkowska, A., Gawłowska, O., & Pawlaczyk, M. (2016). Assessing gait and balance impairment in elderly residents of nursing homes. *J Phys Ther Sci*, 28, 2486–2490.
- Boulgarides, L.K., McGinty, S.M., Willett, J.A., & Barnes, C.W. (2003). Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. *Phys Ther* 83, 328e39.
- Brouwer, B., Musselman, K., & Culham, E. (2004). Physical function and health status among seniors with and without a fear of falling. *Gerontology*, 50, 135–141.
- Brown, L.A., Shumway-Cook, A., & Woollacott, M.H. (1999). Attentional demands and postural recovery: the effects of aging. *J Gerontol A Biol Sci Med Sci*, 54(4), 165-171.
- Bugnariu, N., Sveistrup, H. (2006). Age-related changes in postural responses to externally- and self-triggered continuous perturbations. *Arch Gerontol Geriatr*, 42(1), 73-89.
- Carvalho, MJ., Marques, E., Mota, J. (2009). Training and detraining effects on functional fitness after a multicomponent training in older women. *Gerontology*, 55, 41-48.

- Chen, H.C., Schultz, A.B., Ashton-Miller, J.A., Giordani, B., Alexander, N.B., & Guire, K.E. (1996). Stepping over obstacles: Dividing attention impairs performance of old more than young adults. *J Gerontol A Biol Sci Med Sci*, 51, 116–122.
- Collie, A., Maruff, P., Darby, D.G., & McStephen, M. (2003). The effects of practice on the cognitive test performance, of neurologically normal individuals assessed at brief test–retest intervals. *J Int Neuropsychol Soc*, 9, 419–428.
- Dahlin, E., Neely, A.S., Larsson, A., Backman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the striatum. *Science*, 320, 1510–1512.
- de Bruin, E.D., van Het Reve, E., & Murer, K. (2013). A randomized controlled pilot study assessing the feasibility of combined motor-cognitive training and its effect on gait characteristics in the elderly. *Clin Rehabil*, 27(3), 215-225.
- Desjardins-Crépeau, L., Berryman, N., Fraser, S.A., Vu, T.T., Kergoat, M.J., Li, K.Z., Bosquet, L., & Bherer, L. (2016). Effects of combined physical and cognitive training on fitness and neuropsychological outcomes in healthy older adults. *Clin Interv Aging*, 19(11), 1287-1299.
- Diamantopoulos, I.I., Clifford, E., & Birchall, J.P. (2003). Short-term learning effects of practice during the performance of the tandem romberg test. *Clin Otolaryngol*. 28, 308-313.
- Dorfman, M., Herman, T., Brozgol, M., Shema, S., Weiss, A., Hausdorff, J.M., & Mirelman, A. (2014). Dual-task training on a treadmill to improve gait and cognitive function in elderly idiopathic fallers. *J Neurol Phys Ther*, 38(4), 246-253.

- Dunn, J.E., Furner, S.E., & Miles, T.P. (1993). Do falls predict institutionalization in older persons? An analysis of data from the longitudinal study of aging. *J Aging Health*, 5(2), 194-207.
- Eggenberger, P., Schumacher, V., Angst, M., Theill, N., & de Bruin, ED. (2015). Does multicomponent physical exercise with simultaneous cognitive training boost cognitive performance in older adults? A 6-month randomized controlled trial with a 1-year follow-up. *Clin Interv Aging*, 17(10), 1335-1349.
- Falbo, S., Condello, G., Capranica, L., Forte, R., & Pesce, C. (2016). Effects of physical-cognitive dual task training on executive function and gait performance in older adults: A randomized controlled trial. *Biomed Res Int*, Dec 8. Epub ahead of print.
- Falletti, M.G., Maruff, P., Collie, A., & Darby, D.G. (2006). Practice effects associated with the repeated assessment of cognitive function using the CogState battery at 10-minute, one week and one month test-retest intervals. *J Clin Exp Neuropsychol*, 28, 1095-112.
- Fraizer, E.V., & Mitra, S. (2008). Methodological and interpretive issues in posture-cognition dual-tasking in upright stance. *Gait Posture*, 27, 271-279.
- Gill, J., Allum, J.H., Carpenter, M.G., Held-Zjolkowska, M., Adkin, A.L., Honegger, F., & Pierchala, K. (2001). Trunk sway measures of postural stability during clinical balance tests: Effects of age. *J Gerontol A Biol Sci Med Sci*, 56(7), 438-447.
- Gillespie, L.D., Robertson, M.C., Gillespie, W.J., Sherrington, C., Gates, S., Clemson, L.M., & Lamb, S.E. (2012). Interventions for preventing falls in older people living in the community. *Cochrane Database Syst Rev*, 12(9), CD007146.

- Goble, D.J., Coxon, J.P., Wenderoth, N., Van Impe, A., & Swinnen, S.P. (2009). Proprioceptive sensibility in the elderly: degeneration, functional consequences and plastic-adaptive processes. *Neurosci Biobehav Rev*, 33(3), 271-278.
- Granacher, U., Muehlbauer, T., Bridenbaugh, S., Bleiker, E., Wehrle, A., & Kressig, R.W. (2010). Balance training and multi-task performance in seniors. *Int J Sports Med*, 31(5), 353-358.
- Green, C.S., and Bavelier, D. (2008). Exercising your brain: A review of human brain plasticity and training-induced learning. *Psychol Aging*, 23, 692–701.
- Gregory, M.A., Gill, D.P., Zou, G., Liu-Ambrose, T., Shigematsu, R., Fitzgerald, C., Hachinski, V., & Petrella, R.J. (2016). Group-based exercise combined with dual-task training improves gait but not vascular health in active older adults without dementia. *Arch Gerontol Geriatr*, 63, 18-27.
- Hall, CD., Miszko, T., & Wolf, SL. (2009). Effects of Tai Chi intervention on dual-task ability in older adults: A pilot study. *Arch Phys Med Rehabil*, 90(3), 525–529.
- Halvarsson, A., Oddsson, L., Franzén, E., & Ståhle, A. (2016). Long-term effects of a progressive and specific balance-training programme with multi-task exercises for older adults with osteoporosis: A randomized controlled study. *Clin Rehabil*, 30(11), 1049-1059.
- Hamacher, D., Hamacher, D., Rehfeld, K., & Schega, L. (2016). Motor-cognitive dual-task training improves local dynamic stability of normal walking in older individuals. *Clin Biomech*, 32, 138-141.
- Harley, C., Wilkie, R.M., & Wann, J.P. (2009) Stepping over obstacles: Attention demands and aging. *Gait Posture*, 29(3), 428-432.

- Health Canada, Canada's Aging Population. Ottawa: Government of Canada, 2002.
- Ho, M.C., Chou, C.Y., Huang, C.F., Lin, Y. T., Shih, C.S., Han, S.Y., Shen, M.H., Chen, T.C., Liang, C.L., & Liu, C.J. (2012). Age-related changes of task-specific brain activity in normal aging. *Neurosci Lett*, 507, 78–83.
- Horak, F.B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age Ageing*, 35(2), 7-11.
- Howe, T.E., Rochester, L., Neil, F., Skelton, D.A., & Ballinger, C. (2012). Exercise for improving balance in older people. *The Cochrane Collaboration*, 5, 1-294.
- Howland, J., Peterson, E.W., Levin, W.C., Fried, L., Pordon, D., & Bak, S. (1993). Fear of falling among the community-dwelling elderly. *J Aging Health*, 5(2), 229-243.
- Huang, H.J., & Mercer, V.S. (2001). Dual-task methodology: Applications in studies of cognitive and motor performance in adults and children. *Ped Phys Ther*, 13, 133-140.
- Hyndman, D., & Ashburn, A. (2004). “Stops walking when talking” as a predictor of falls in people with stroke living in the community. *J Neurol Neurosurg Psychiatry*, 75(7), 994–997.
- Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.
- KelloggGroup. (1987). The prevention of falls in later life. A report of the kellogg international work group on the prevention of falls by the elderly. *Dan Med Bull*, 34(4), 1-24.
- Kiel, D.P., O’Sullivan, P., Teno, J.M., & Mor, V. (1991). Health care utilization and functional status in the aged following a fall. *Med Care*, 29(3), 221-228.
- King, M.B., & Tinetti, M.E. (1995). Falls in community-dwelling older persons. *J Am Geriatr Soc*, 43(10), 1146-1154.

- Kosorok, M.R., Omenn, G.S., Diehr, P., Koepsell, T.D., & Patrick, D.L. (1992). Restricted activity days among older adults. *Am J Public Health*, 82(9), 1263-1267.
- Kramer, A.F., Larish, J., & Strayer, D.L. (1995). Training for attentional control in a dual task setting: A comparison of young and old adults. *J Exp Psychol Appl*, 1, 50–76.
- Lacroix, A., Kressig, R.W., Muehlbauer, T., Gschwind, Y.J., Pfenninger, B., Bruegger, O., & Granacher, U. (2016). Effects of a supervised versus an unsupervised combined balance and strength training program on balance and muscle power in healthy older adults: A randomized controlled trial. *Gerontology*, 62(3), 275-288.
- Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Upright standing and gait: are there changes in attentional requirements related to normal aging? *Exp Aging Res*, 22(2), 185-198.
- Law, L.L., Barnett, F., Yau, M.K., & Gray, M.A. (2014). Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: A systematic review. *Ageing Res Rev*, 15, 61–75.
- Li, KZ., Roudaia, E., Lussier, M., Bherer, L., Leroux, A., & McKinley, P.A. (2010). Benefits of cognitive dual-task training on balance performance in healthy older adults. *J Gerontol A Biol Sci Med Sci*, 65(12), 1344–1352.
- Lim, H.S., & Yoon, S. (2014a). The influence of short-term aquatic training on obstacle crossing in gait by the elderly. *J Phys Ther Sci*, 26, 1219–1222.
- Lim, H.S., & Yoon, S. (2014b). The training and detraining effects of 8 weeks of water exercise on obstacle avoidance in gait by the elderly. *J Phys Ther Sci*, 26, 1215–1218.
- Lord, S.R. (2006). Visual risk factors for falls in older people. *Age Ageing*, 35(2), 42-45.

- Lussier, M., Bugajska, A., & Bherer, L. (2016). Specific transfer effects following variable priority dual-task training in older adults. *Restor Neurol Neurosci*, Jun 25 Epub ahead of print.
- Lussier, M., Gagnon, C., & Bherer, L. (2012). An investigation of response and stimulus modality transfer effects after dual-task training in younger and older. *Front Hum Neurosci*, 18(6),129.
- Makizako, H., Furuna, T., Shimada, H., Ihira, H., Kimura, M., Uchiyama, E., & Oddsson, L.I. (2010). Association between a history of falls and the ability to multi-task in community-dwelling older people. *Aging Clin Exp Res*, 22(5-6), 427-432.
- Manor, B., Costa, M.D., Hu, K., Newton, E., Starobinets, O., Kang, H.G., Peng, C.K., Novak, V., & Lipsitz, L.A. (2010). Physiological complexity and system adaptability: Evidence from postural control dynamics of older adults. *J Appl Physiol*, 109(6), 1786–1791.
- Marusic, U., Giordani, B., Moffat, S.D., Petrič, M., Dolenc, P., Pišot, R., & Kavcic, V. (2016). Computerized cognitive training during physical inactivity improves executive functioning in older adults. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn*, 12, 1-21.
- Massion J. (1994). Postural control system. *Curr Opin Neurobiol*, 4(6), 877-887.
- McCulloch, K.L., Mercer, V., Giuliani, C., & Marshall, S. (2009). Development of a clinical measure of dual-task performance in walking: Reliability and preliminary validity of the walking and remembering test. *J Geriatr Phys Ther*, 32(1), 2-9.
- Mozolic, J.L., Long, A.B., Morgan, A.R., Rawley-Payne, M., & Laurienti, P.J. (2011). A cognitive training intervention improves modality-specific attention in a randomized controlled trial of healthy older adults. *Neurobiol Aging*, 32(4), 655–668.

- Nakano, M.M., Otonari, T.S., Takara, K.S., Carmo, C.M., & Tanaka, C. (2014). Physical performance, balance, mobility, and muscle strength decline at different rates in elderly people. *J Phys Ther Sci*, 26, 583–586.
- Nematollahi, A., Kamali, F., Ghanbari, A., Etminan, Z., & Sobhani, S. (2016). Improving balance in older people: A double-blind randomized clinical trial of three modes of balance training. *J Aging Phys Act*, 24(2), 189-195.
- Nishiguchi, S., Yamada, M., Tanigawa, T., Sekiyama, K., Kawagoe, T., Suzuki, M.,... Tsuboyama, T. (2015). A 12-week physical and cognitive exercise program can improve cognitive function and neural efficiency in community-dwelling older adults: A randomized controlled trial. *J Am Geriatr Soc*, 63(7), 1355-1363.
- Nordahl, S.H., Aasen, T., Dyrkorn, B.M., Eidsvik, S., & Molvaer, O.I. (2000). Static stabilometry and repeated testing in a normal population, *Aviat Space Environ Med*, 71, 889-893.
- Oberg, E. (2007). Physical Activity Prescription: Our Best Medicine. *Integrative Medicine*, 6(5), 18-22.
- Oswald, W.D., Gunzelmann, T., Rupprecht, R., & Hagen, B. (2006). Differential effects of single versus combined cognitive and physical training with older adults: the SimA study in a 5-year perspective. *Eur J Ageing*, 3, 179–192.
- Owen, A.M., Hampshire, A., Grahn, J. A., Stenton, R., Dajani, S., Burns, A. S., & Ballard, C.G. (2010). Putting brain training to the test. *Nature*, 465, 775–778.
- Pan, H.F., Hsu, H.C., Chang, W.N., Renn, J.H., & Wu, H.W. (2016). Strategies for obstacle crossing in older adults with high and low risk of falling. *J Phys Ther Sci*, 28(5), 1614-1620.

- Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychol Bull*, 116, 220-244.
- Patla, A. (1997). Understanding the roles of vision in the control of human locomotion. *Gait Posture*, 5, 54-69.
- Pichierri, G., Coppe, A., Lorenzetti, S., Murer, K., & de Bruin, ED. (2012). The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: A randomized controlled pilot study. *Clin Interv Aging*, 7, 175-184.
- Pichierri, G., Wolf, P., Murer, K., & de Bruin, ED. (2011). Cognitive and cognitive-motor interventions affecting physical functioning: a systematic review. *BMC Geriatr*, 11, 29.
- Pichierri, G., Murer, K., & de Bruin, E.D. (2012). A cognitive-motor intervention using a dance video game to enhance foot placement accuracy and gait under dual task conditions in older adults: A randomized controlled trial. *BMC Geriatr*, 12, 74.
- Plummer-D'Amato, P., Cohen, Z., Dae, N.A., Lawson, S.E., Lizotte, M.R., & Padilla, A. (2012). Effects of once weekly dual-task training in older adults: A pilot randomized controlled trial. *Geriatr Gerontol Int*, 12(4), 622-629.
- Rawson, N.S. & Saad, F. (2010). The aging male population and medical care for benign prostatic hyperplasia in Canada. *Can Urol Assoc J*, 4(2), 123-127.
- Remaud, A., Boyas, S., Lajoie, Y., & Bilodeau, M. (2013). Attentional focus influences postural control and reaction time performances only during challenging dual-task conditions in healthy young adults. *Exp Brain Res*, 231(2), 219-229.

- Rhea, C.K., Silver, T.A., Hong, S.L., Ryu, J.H., Studenka, B.E., Hughes, C.M.L., Haddad, J.M. (2011). Noise and complexity in human postural control: Interpreting the different estimations of entropy. *PLoS One*, 6:e17696.
- Salminen, T., Frensch, P., Strobach, T., & Schubert, T. (2016). Age-specific differences of dual n-back training. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn*, 23(1), 18-39.
- Schättin, A., Arner, R., Gennaro, F., & de Bruin, ED. (2016). Adaptations of prefrontal brain activity, executive functions, and gait in healthy elderly following exergame and balance training: A randomized-controlled study. *Front Aging Neurosci*, 23(8), 278.
- Sekiya, N., Nagasaki, H., Ito, H., & Furuna, T. (1997). Optimal walking in terms of variability in step length. *J Orthop Sports Phys Ther*, 26(5), 266-272.
- Shaffer, S.W., & Harrison, A.L. (2007). Aging of the somatosensory system: A translational perspective. *Phys Ther*, 87(2), 193-207.
- Sherrington, C., Whitney, J.C., Lord, S.R., Herbert, R.D., Cumming R.G., & Close, J.C. (2008). Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr Soc*, 56(12), 2234-2243.
- Sherrington, C., Michaleff, Z.A., Fairhall, N., Paul, S.S., Tiedemann, A., Whitney, J., Cumming, R.G., Herbert, R.D., Close, J.C., & Lord, S.R. (2016). *Br J Sports Med*, Oct 4, Epub ahead of print.
- Shumway-Cook, A., Brauer, S., & Woollacott, M. (2000). Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Phys Ther*, 80(9), 896-903.

- Shumway-Cook, A., Gruber, W., Baldwin, M., & Liao, S. (1997). The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. *Phys Ther*, 77(1), 46-57.
- Silsupadol, P., Lugade, V., Shumway-Cook, A., van Donkelaar, P., Chou, LS., Mayr, U., & Woollacott, MH. (2009). Training-related changes in dual-task walking performance of elderly persons with balance impairment: a double-blind, randomized controlled trial. *Gait Posture*, 29(4), 634–639.
- Silsupadol, P., Shumway-Cook, A., Lugade V, van Donkelaar, P., Chou, LS., Mayr, U., & Woollacott, MH. (2009). Effects of single-task versus dual-task training on balance performance in older adults: A double-blind, randomized controlled trial. *Arch Phys Med Rehabil*, 90(3), 381–387.
- Silsupadol, P., Siu, KC., Shumway-Cook, A., & Woollacott, MH. (2006). Training of balance under single- and dual-task conditions in older adults with balance impairment. *Phys Ther*, 86(2), 269–281.
- Smarrisk. (2009). The economic burden of injury in Canada. SMARTRISK, Toronto, ON.
- Smith, E., Walsh, L., Doyle, J., Greene, B., & Blake, C. (2016). The reliability of the quantitative timed up and go test (QTUG) measured over five consecutive days under single and dual-task conditions in community dwelling older adults. *Gait Posture*, 43, 239-244.
- Smith-Ray, RL., Makowski-Woidan, B., & Hughes, SL. (2014). A randomized trial to measure the impact of a community-based cognitive training intervention on balance and gait in cognitively intact black older adults. *Health Educ Behav*, Oct, 41, 62S-9S.
- Stelmach, G. E., & Worringham, C. J. (1985). Sensorimotor deficits related to postural stability. Implications for falling in the elderly. *Clin Geriatr Med*, 1(3), 679-694.

- Stobach, T., Frensch, P., Hermann, M., & Schubert, T. (2012a). Age- and practice-related influences on dual-task costs and compensation mechanisms under optimal conditions of dual-task performance. *Neuropsychol Dev Cog B Aging Neuropsychol Cogn*, 19, 222-247.
- Stobach, T., Frensch, P., Hermann, M., & Schubert, T. (2012b). Testing the limits of optimizing dual-task performance in younger and older adults. *Front Hum Neurosci*, 5(6), 39.
- Thiebaud, R.S., Funk, M.D., & Abe, T. (2014). Home-based resistance training for older adults: A systematic review. *Geriatr Gerontol Int*, 14, 750-757.
- Tideiksaar, R. (1996). Preventing falls: How to identify risk factors, reduce complications. *Geriatrics*, 51(2), 43-46.
- Tinetti, M.E., & Williams, C.S. (1998). The effect of falls and fall injuries on functioning in community-dwelling older persons. *J Gerontol A Biol Sci Med Sci*, 53(2), 112-119.
- Tinetti, M.E., Mendes de Leon, C.F., Doucette, J.T., & Baker, D.I. (1994). Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. *J Gerontol*, 49(3), 140-147.
- Tinetti, M.E., Speechley, M., & Ginter, S.F. (1988). Risk factors for falls among elderly persons living in the community. *N Engl J Med*, 319(26), 1701-1707.
- Turcotte, M., & Schellenberg, G. (2006). A portrait of seniors in Canada. Statistics Canada. Ottawa: Minister of Industry.
- Uemura, K., Yamada, M., Nagai, K., Tateuchi, H., Mori, S., Tanaka, B., & Ichihashi, N. (2012). Effects of dual-task switch exercise on gait and gait initiation performance in older adults: Preliminary results of a randomized controlled trial. *Arch Gerontol Geriatr*, 54(2), 167-171.

- van Diest, M., Stegenga, J., Wörtche, HJ., Verkerke, GJ., Postema, K., & Lamoth, CJ. (2016). Exergames for unsupervised balance training at home: A pilot study in healthy older adults. *Gait Posture*, 44,161-167.
- van het Reve, E., & de Bruin, ED. (2014). Strength-balance supplemented with computerized cognitive training to improve dual task gait and divided attention in older adults: A multicenter randomized-controlled trial. *BMC Geriatr*, Dec 15; 14, 134.
- van Iersel, M., Benraad, C., & Olde Rikkert, M. (2007). Validity and reliability of quantitative gait analysis in geriatric patients with and without dementia. *J Am Geriatr Soc*, 55, 632–634.
- Verghese, J., Mahoney, J., Ambrose, AF., Wang, C., & Holtzer, R. (2010). Effect of cognitive remediation on gait in sedentary seniors. *J Gerontol A Biol Sci Med Sci*, 65(12), 1338–1343.
- Verhaeghen, P. & Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analyses. *Neurosci Biobehav Rev*, 26(7), 849-857.
- Weeks, D.L., Forget, R., Mouchnino, L., Gravel, D., & Bourbonnais, D. (2003). Interaction between attention demanding motor and cognitive tasks and static postural stability. *Gerontol*, 49, 225-232.
- Wolf, SL., Barnhart, HX., Ellison, GL., & Coogler, CE. (1997). The effect of tai chi quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. Frailty and Injuries: Cooperative studies on intervention techniques. *Phys Ther*, 77(4), 371-381.
- Wollesen, B., & Voelcker-Rehage, C. (2013). Training effects on motor–cognitive dual-task performance in older adults. *Eur Rev Aging Phys Act*, 11(1), 5-24.

- Wollesen, B., Voelcker-Rehage, C., Willer, J., Zech, A., & Mattes, K. (2015). Feasibility study of dual-task-managing training to improve gait performance of older adults. *Aging Clin Exp Res*, 27(4), 447-455.
- Wongcharoen, S., Sungkarat, S., Munkhetvit, P., Lugade, V., & Silsupadol, P. (2016). Home-based interventions improve trained, but not novel, dual-task balance performance in older adults: A randomized controlled trial. *Gait Posture*, 52, 147-152.
- Woollacott, M.H., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait Posture*, 16(1), 1-14.
- Yamada, M., Aoyama, T., Hikita, Y., Takamura, M., Tanaka, Y., Kajiwara, Y., Nagai, K., Uemura, K., Mori, S., & Tanaka, B. (2011). Effects of a DVD-based seated dual-task stepping exercise on the fall risk factors among community-dwelling elderly adults. *Telemed J E Health*, 17(10), 768–772.
- Yogev-Seligmann, G., Hausdorff, J.M., & Giladi, N. (2012). Do we always prioritize balance when walking? Towards an integrated model of task prioritization. *Mov Disord*, 27(6), 765–770.

CHAPTER 3: STUDY 1

Examining the stability of dual-task posture and reaction time measures in older adults over five sessions: A pilot study

A version of this article has been published in Aging Clinical and Experimental Research, and has been formatted accordingly. Both Drs. Yves Lajoie and Nicole Paquet give their consent to the inclusion of this manuscript in the current dissertation.

Deborah A. Jehu^a, Nicole Paquet^{a,b} and Yves Lajoie^a

^a School of Human Kinetics, University of Ottawa, 125, University Avenue, Ottawa, Ontario, K1N 6N5, Canada

^b School of Rehabilitation Sciences, University of Ottawa, 451 Smyth road, Ottawa, Ontario K1H 8M5, Canada.

Corresponding author

Nicole Paquet, PhD
School of Rehabilitation Sciences
University of Ottawa
451 Smyth Road
Ottawa (Ontario)
H3W 1W5, Canada
Tel. (613) 562-5800, ext. 8039
Fax. (613) 562-5428
Email. npaquet@uottawa.ca

ABSTRACT. Background and aim: Improved performance may be inherent due to repeated exposure to a testing protocol, however, limited research has examined this phenomenon in postural control. The aim was to determine the influence of repeated administration of a dual-task testing protocol once per week for 5 weeks on postural sway and reaction time.

Methods: Ten healthy older adults (67.0 ± 6.9 years) stood on a force plate for 30 s in feet-apart (FA) and semi-tandem (ST) positions while completing simple reaction time (SRT) and choice reaction time (CRT) tasks. They were instructed to stand as still as possible while verbally responding as fast as possible to the stimuli. **Results:** No significant differences in postural sway were shown over time ($p > 0.05$). A plateau in average CRT emerged as the time effect revealed longer CRT during session 1 compared to sessions 3-5 ($p < 0.05$). Furthermore, the time effect for within-subject variability of CRT uncovered no plateaus as it was less variable in session 5 than sessions 1-4 ($p < 0.05$). **Discussion:** The lack of a plateau in variability of CRT may have emerged as older adults may require longer to reach optimal performance potential in a dual-task context. **Conclusion:** Postural sway and SRT were stable over the 5 testing sessions, but variability of CRT continued to improve over time. These findings form a basis for future studies to examine the potential performance-related improvements due to repeated exposure to a testing protocol in a dual-task setting in a larger sample size.

Keywords

Repeated assessment, Dual-task, Posture, Reaction time, Task complexity, Older adults

INTRODUCTION

Despite the widespread use of repeated testing protocols, such as those administered for interventions (e.g., baseline, post treatment, follow-up), learning effects may be inherent due to repeated exposure and not due to the treatment. Accordingly, the current study aimed to determine whether improvements in performance would occur simply as a result of serial administration of the same postural and reaction time testing protocol once per week for 5 weeks in older adults. There have been mixed findings with respect to whether improved performance occurs after repeated procedures. In fact, research has shown a 25% gradual reduction in center of pressure (COP) sway velocity within the first 5 testing sessions, to a maximum of 34% after 15 consecutive days when standing with eyes open and closed [1]. Other previous work has examined postural sway across 5 testing sessions and found improved posturography after 10 sessions of standing on firm and foam surfaces, with the improvement being even greater when standing on foam with eyes closed [2]. Furthermore, Nordahl et al. [2] found that performance improvements were heightened when the interval between testing sessions was shortened. This suggests that having the various testing sessions close in proximity elicits even greater improvements in standing posture.

However, other studies have shown no improvements in quiet standing over repeated testing sessions. For example, one study found no improvements over 5 testing sessions after having participants practice tandem standing with their eyes open and closed and on a firm and foam surface daily for 10 consecutive days [3]. Similarly, other studies showed no difference in force plate measures between testing sessions in healthy adults while standing on two legs with eyes open or closed over 5 sessions [4], or over 10 sessions [5]. Indeed, it has been proposed that there is neither a consistent improvement nor decrement in postural sway over 5 days, but rather

high variability [6]. However, it is possible that the lack of short-term improvements in standing posture may stem from a relatively brief length in practice. Additionally, methodological differences between the various testing protocols may also explain the discrepancy in findings among studies. For example, the aforementioned studies had different outcome measures, different postural tests, as well as a different number of testing sessions, which may account for some of the variability in results. Finally, these studies have only examined healthy young and middle aged participants, which underlines the need for further exploration in older adults.

Other research examining young and older adults while completing seated repeated cognitive-motor testing has also found more pronounced improvements between the first two testing sessions [7,8]. Participants completed a battery of cognitive-motor tasks on a computer that involved playing cards over four sessions in one day. Some of the various tasks involved simple RT and choice RT. Results demonstrated a significant improvement between the first compared to the second testing session; however, in general no further improvements were shown across the subsequent sessions. In contrast, experiments training visual and auditory RT tasks in older adults have shown steady improvements throughout the training sessions, without reaching a plateau in performance by 8 [9] and 21 sessions [10]. In fact, other work has reported that dual-task practice can lead to efficient integration of the two tasks, and that the transfer of skills is apparent provided at least one of the previous tasks has been automatized in young adults [11]. From these findings, it can be surmised that repeated testing procedures involving cognitive-motor tasks may not reach a plateau in performance until after 21 testing sessions, which may be suggestive of cognitive plasticity in older adults, or that they require a large amount of practice before reaching their maximum performance potential.

Repeated testing protocols inherent to cognitive training interventions have shown mixed findings with respect to the effectiveness across cognitive domains (e.g., memory, reaction time, processing speed, etc.) over time [12]. For instance, three experiments [13-15] reported improvements on visual spatial abilities (Road Sign Test), but no impact of training on executive function (Trail Making Test Part B) or psychomotor speed (Digit Symbol Substitution Test). Other experiments have found improvements in reaction time after 20 sessions of computerized balance training or virtual reality balance training [16], in working memory after 2 sessions of computerized cognitive training [17], and in attention and memory after 8 sessions of computerized cognitive training [18]; however, it is unknown whether these findings stem from the intervention itself or the repeated testing protocol pre and post training because these experiments had no control group.

Improvements in single manual tasks have also been revealed after repeated testing procedures. For instance, the ruler-drop test was repeated in college-aged athletes between two consecutive seasons [19]. Participants placed their thumb and index finger in a “u” shape at the base of the ruler; upon the release of the ruler, participants grasped the ruler as fast as possible. A significant decrease of approximately 11 ms in reaction time (RT) was observed between testing sessions. Although their aim was to compare the test-retest reliability of this task, performance was indeed affected by practice effects. Recently, follow-up research was conducted to determine if the ruler-drop test was susceptible to improvement after serial administration [20]. Ten trials of the ruler-drop test were completed over 10 sessions across a 5 week period. Results showed that there was a significant decrease in RT between the first and second testing session by approximately 7 ms, and there was approximately a 13 ms improvement in RT between the

first and tenth testing session. The most pronounced improvement occurred between the first two testing sessions for this simple RT task.

In sum, this compilation of research reveals the impact of replicated testing procedures, and the potential successive improvements, simply due to the exposure of the testing protocol. It also highlights the need for further attention in this area due to lack of research examining the effects of repeated exposure to dual-task protocols in older adults. In addition, conducting more than two testing sessions enabled us to better determine the longitudinal extent to which practice effects occur in older adults. Thus, the overarching purpose of this pilot study was to examine the influence of serial administration of the same testing protocol once per week for 5 weeks by employing two levels of difficulty for both the postural tasks (i.e., feet apart (FA) versus semi-tandem (ST)), and the RT tasks (i.e., simple reaction time (SRT) versus choice reaction time (CRT)) in single and dual-task contexts in older adults. Specifically, the objective was to compare the effect of repeated exposure on COP measures, RT, and task complexity (Feet position: FA and ST; RT: SRT and CRT). Our primary hypothesis was that no improvements in posture would emerge over the 5 sessions as previous research examining 94 experiments revealed weak evidence towards improvements in balance following training [21]. Additionally, we hypothesized that SRT would have a stable performance after repeated exposure due to its potential ceiling effect [22], but CRT would show an improvement across testing sessions [23]. Our secondary hypotheses were that ST tasks would exhibit greater postural sway than FA tasks, and that CRT would exhibit longer RT than SRT tasks, as shown by previous work [24].

METHODS

Participants

Ten healthy older adults (5 males and 5 females; age: 67 ± 6.9 years; weight: 75.9 ± 11.8 kg; height: 172.2 ± 9.4 cm) were recruited for this study. Inclusion criteria consisted of older adults aged 60 years and older, having no self-reported musculoskeletal, neurological or sensory deficits that may affect balance, taking no medications that may affect balance, having no falls with no obvious reason, having normal or corrected to normal vision, living independently in the community, walking without an assistive device, or having a score less than 63 on the Godin Leisure-Time Physical Activity Questionnaire (Godin) obtaining 24 or greater on the Mini Mental State Exam (MMSE), and able to discriminate between high and low pitched auditory beeps.

Procedure

Participants began the testing session by reading and signing the informed consent form approved by the University of Ottawa Research Ethics Board. To describe the sample, participants completed a demographic questionnaire (i.e. age, sex, and history of disease), the MMSE, and the Godin. Across all experimental conditions, participants were asked to stand on a force platform with their FA or feet in ST and arms at their sides while directing their gaze at an eye-level target 3 m in front of the force platform. The position of the participants' feet was marked on the force platform to ensure consistent foot placement across trials and sessions. In conjunction with the 30 s postural task, participants were asked to perform two RT tasks: SRT and CRT. During the SRT trials, participants were asked to verbally respond "tie" to random high pitched auditory cues throughout the trials. Between 5 and 7 stimuli were presented per trial and ranged from 3 to 7 seconds apart. During the CRT trials, participants were presented with

random low and high auditory stimuli and were asked to respond “tow” and “tie”, respectively. These words were chosen as they have a hard consonant and they also resemble the words “high” and “low”, which were the two different pitches used. Between 5 and 7 stimuli were administered per trial and ranged from 3 to 8 seconds apart, of which 2 to 4 were low pitched. If participants incurred two or more errors of omission or commission (i.e., a mistake) in a single trial, the trial was repeated. Three 30 s trials were performed for each of the conditions (i.e., FA, FA SRT, FA CRT, ST, ST SRT, and ST CRT). Prior to the experimental conditions, a familiarization period was performed, including FA, FA SRT, and FA CRT for 30 s, at the beginning of each testing session over the 5 weeks. The instructions were to stand as still as possible while verbally responding as fast as possible, when applicable.

Because this is part of a larger study, it should be noted that the dual-task postural testing protocol (i.e., Study 1) was performed first, followed by the functional mobility testing protocol (i.e., Study 3), followed by the dual-task obstacle clearance testing protocol (i.e., Study 2).

Data and statistical analyses

An mp3 recorder (Sony MP3 IC Recorder (ICD-UX70), San Diego, CA) was attached to the participants’ arm and used to capture both the high and low auditory stimuli emitted by a piezoelectric speaker and the verbal responses in order to determine RT. The high-pitched signal was administered at a frequency of 2850 Hz whereas the low pitched signal was administered at a frequency of 970 Hz. The Audacity software system was used to process RT, which was computed manually using vertical cursors from the start of the verbal response minus the onset of the auditory cue in ms.

An AMTI force plate (ORG-6-1000, Don Mills, ON, Canada) was used as a proxy to measure COP at a sampling frequency of 500 Hz. COP Velocity, COP Standard Deviation (SD)

in the medial-lateral (ML) and anterior-posterior (AP) directions, COP Path Length, and 95% Area Ellipse measures were calculated for each postural test. Note that COP Path Length is the length of the COP Displacement trajectory and is therefore independent of direction [25].

Previous work has shown excellent test-retest reliability and high intra-class correlation coefficient values of similar COP measures and RT [26], which affirms the use of these outcome variables. Trials were averaged for each experimental condition and these averages were used for analysis.

Separate three-way analyses of variance (ANOVAs) were performed on Session (1-5) x Stance (FA, ST) x RT difficulty (SRT, CRT) with repeated measures on each factor for Velocity, COP SD, COP Path Length, COP 95% Area Ellipse, average RT and within-subject SD of RT.

When applicable, post hoc least significant difference comparisons were performed. If

Mauchly's test of Sphericity was violated, the Greenhouse-Geisser correction was performed.

Statistical significance was set to $p < 0.05$.

RESULTS

Stability of COP measures over 5 sessions

No significant changes were derived in any of the COP measures over time: COP Velocity ($F(1,9)=1.20, p>0.05$), COP SD in the ML ($F(1,9)=1.29, p>0.05$) or in the AP directions ($F(1,9)=0.26, p>0.05$), COP Path Length ($F(1,9)=1.27, p>0.05$), or 95% Area Ellipse ($F(1,9)=0.48, p>0.05$).

Effect of the stance tasks on COP measures

Significant main effects of stance were found for COP Velocity ($F(1,9)=40.37, p<0.05, \eta^2=0.83$), COP SD ML ($F(1,9)=164.94, p<0.05, \eta^2=0.95$), COP Path Length ($F(1,9)=47.87, p<0.05, \eta^2=0.86$), and COP Area ($F(1,9)=51.93, p<0.05, \eta^2=0.83$) such that ST tasks showed

significantly greater postural sway than FA tasks (Table 1). No main effect of stance was found for COP SD AP ($F(1,9)=5.09, p>0.05$).

Effect of the RT tasks on COP measures

There was a significant main effect of RT difficulty for COP SD ML ($F(1,9)=4.97, p<0.05, \eta^2=0.38$), COP SD AP ($F(1,9)=7.76, p<0.05, \eta^2=0.49$), and COP Area ($F(1,9)=5.17, p<0.05, \eta^2=0.39$) such that the stance tasks that did not include RT demonstrated greater variability and greater COP Area than the SRT and CRT tasks (Table 2). No main effect of RT difficulty was shown for COP Velocity ($F(1,9)=0.87, p>0.05$) or COP Path Length ($F(1,9)=0.92, p>0.05$).

Stability of RT over 5 sessions

The results showed a significant interaction between Session and RT difficulty ($F(1,9)=4.93, p<0.05, \eta^2=0.38$). Post hoc analyses revealed a significant main effect of Session for CRT ($F(1,9)=6.06, p<0.001, \eta^2=0.43$), such that session 1 showed significantly longer average RT than sessions 3-5 ($p<0.01$) with a trend for significance between sessions 1 and 2 ($p=0.056$), as well as a trend for longer RT between sessions 2 and 3 compared to session 5 ($p=0.057$); however no significant difference in SRT was shown over time ($F(1,9)=0.23, p>0.05$) (Figure 1). A significant Session by RT difficulty interaction effect emerged for within-subject SD of RT ($F(1,9)=3.66, p<0.05, \eta^2=0.31$). Post hoc analyses revealed no significant changes in SD SRT over time ($F(1,9)=1.01, p>0.05$). However, there was a significant main effect of Session for CRT ($F(1,9)=6.05, p<0.01, \eta^2=0.43$) such that there was a significant decrease in SD CRT over time ($p<0.001$) between testing session 1-4 compared to session 5 (Figure 2).

Effect of the stance tasks on RT measures

No significant changes in RT difficulty were exhibited across stance tasks for average RT ($F(1,9)=0.80, p>0.05$) or SD of RT ($F(1,9)=4.39, p>0.05$).

Table 1 Significant main effects for Stance; Mean (SD).

Dependent Variables	FA	FA SRT	FA CRT	ST	ST SRT	ST CRT
COP Velocity (cm/s)	3.57 (0.53)	3.10 (0.55)	3.98 (0.61)	4.61 (0.58)	5.14 (0.77)	5.05 (0.72)
COP SD ML (cm)	0.23 (0.10)	0.22 (0.09)	0.24 (0.09)	0.70 (0.17)	0.65 (0.14)	0.65 (0.13)
COP Path Length (cm)	116.56 (15.71)	117.1 (16.31)	117.55 (18.11)	148.68 (17.15)	152.31 (22.64)	149.36 (21.18)
95% Area (cm ²)	2.00 (1.17)	1.77 (0.91)	1.91 (1.08)	6.78 (2.70)	6.07 (2.61)	5.87 (2.51)

FA feet apart, *ST* semi-tandem, *SD* standard deviation, *COP* center of pressure, *ML* medial-lateral

Table 2 Significant main effects for RT difficulty; Mean (SD).

Dependent Variables	FA	FA SRT	FA CRT	ST	ST SRT	ST CRT
COP SD ML (cm)	0.23 (0.10)	0.22 (0.09)	0.24 (0.09)	0.70 (0.17)	0.65 (0.14)	0.65 (0.13)
COP SD AP (cm)	0.49 (1.28)	0.44 (0.10)	0.44 (0.12)	0.44 (0.10)	0.53 (0.14)	0.51 (0.13)
95% Area (cm ²)	2.00 (1.17)	1.77 (0.91)	1.91 (1.08)	6.78 (2.70)	6.07 (2.61)	5.87 (2.51)

FA feet apart, *ST* semi-tandem, *SD* standard deviation, *COP* center of pressure, *ML* medial-lateral, *AP* anterior-posterior, *RT* reaction time, *SRT* simple reaction time, *CRT* choice reaction time

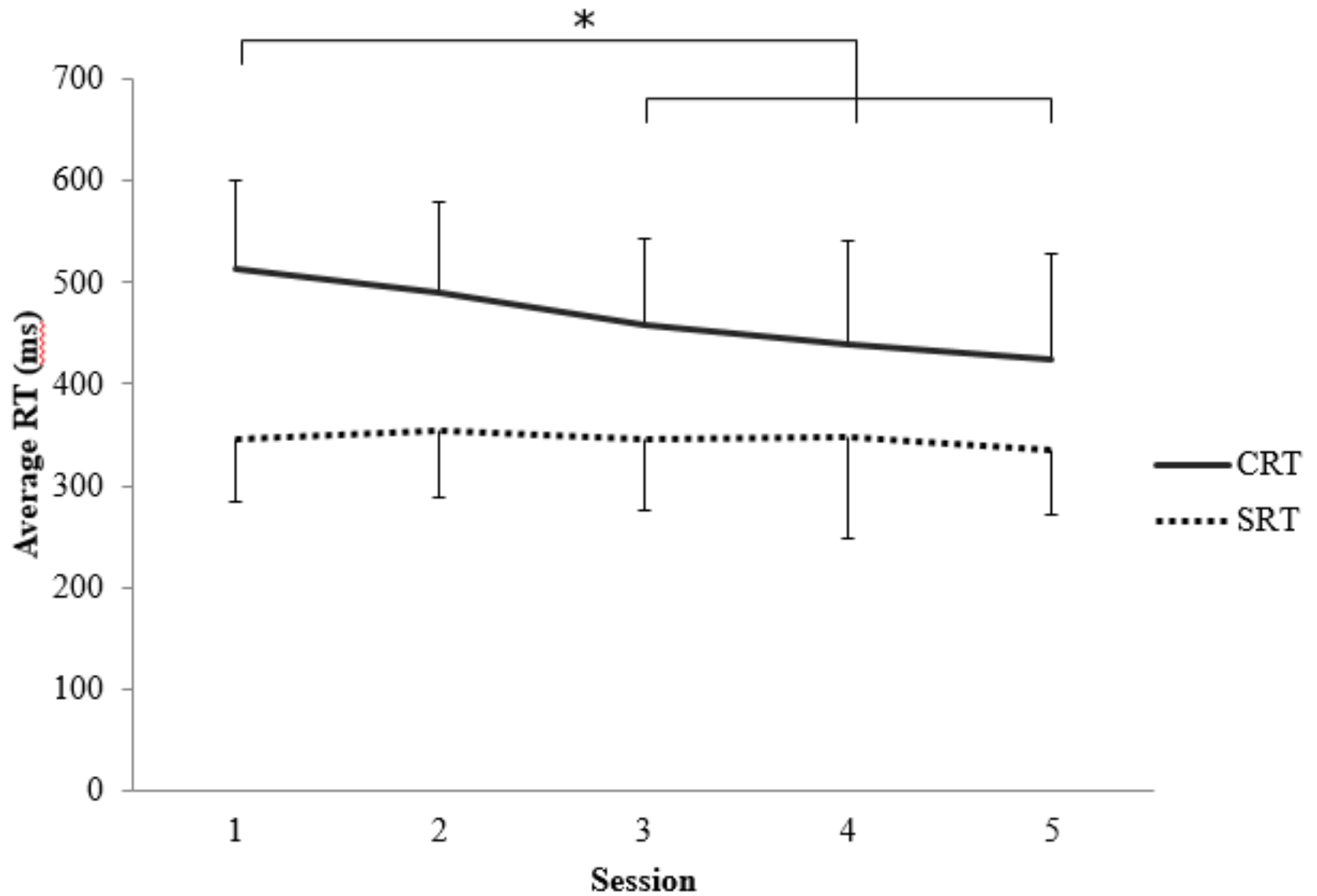


Fig. 1. Average (± 1 SD) simple reaction time (SRT) and choice reaction time (CRT) over 5 sessions. $*p < 0.001$

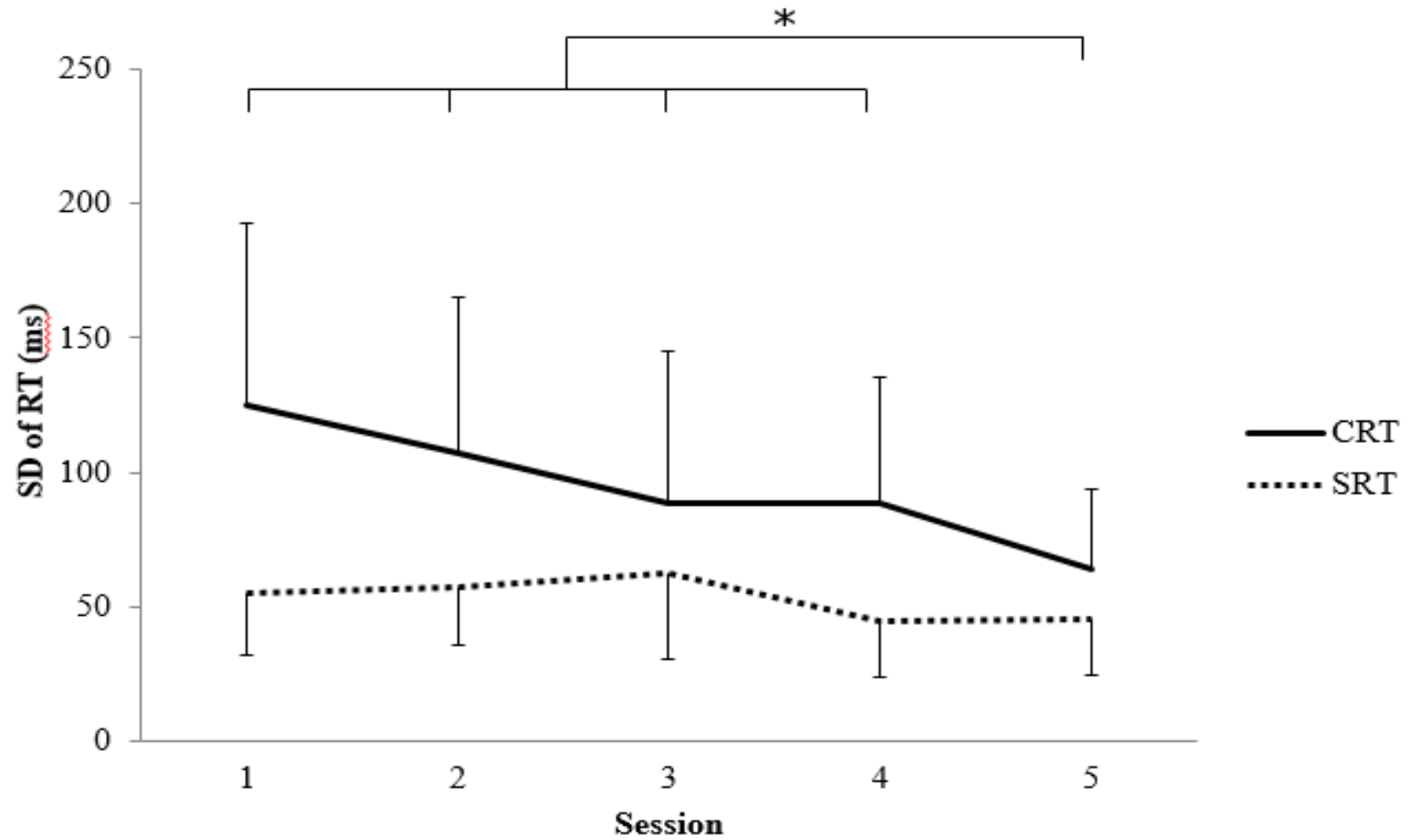


Fig. 2. Within-subject standard deviation (± 1 SD) of simple reaction time (SRT) and choice reaction time (CRT) over 5 sessions.
* $p < 0.001$

Effect of the RT tasks on RT measures

The significant main effects of the RT difficulty revealed that CRT tasks showed significantly longer average RT ($F(1,9)=235.36, p<0.001, \eta^2=0.97$) and greater within-subject variability ($F(1,9)=65.10, p<0.001, \eta^2=0.89$) than SRT tasks.

DISCUSSION

COP measures

This pilot study aimed to expose the role of administering the same testing protocol over 5 weeks on postural performance. We examined this notion in older adults whilst employing a dual-task paradigm. Notably, we found no differences in any of the posturographic measures over the 5 testing sessions under single and dual-task contexts, which confirms our first hypothesis. Our results concur with earlier work that has also found no improvements in postural performance over time in young adults [3, 4, 5]. However, other work has shown improvements after repeated testing procedures in young adults, possibly due to methodological differences [1, 2]. For instance, some methodological differences stem from different outcome measures, different testing protocols, as well as the variability in the number of testing sessions. This stresses the importance of a familiarization period as improvements on outcome variables may not be a function of true improved performance, and may stem from an acclimation to the task.

Balance training can also be thought of as repeated exposure to various balance activities over time. Interestingly, there have been mixed findings with regards to the impact of balance training programs on posture in older adults. For example, a 15-week senior's jazz dance program demonstrated improvements in postural sway as measured by the sensory organization test [27]. In contrast, a 5-week dual-task balance training program for older adults showed no improvements in postural sway but did show improvements in obstacle avoidance [28]. These

discrepancies in findings may emerge from the differences in the length or type of the training program. Furthermore, the lack of short-term changes in COP measures in the present study may emanate from the relatively brief length in practice as only 5 testing sessions were involved. Therefore, we propose that improvements in postural sway following a balance intervention may be exhibited due to the intervention itself as opposed to the repeated administration of a dual-task testing protocol.

According to our second hypothesis, the current study also demonstrates that there was a significant increase in COP SD in the medial-lateral direction, Velocity, and Path Length when standing in ST compared to FA. These findings concur with previous research that has shown that as the complexity of the postural task increases, in this case, a decrease in the base of support (FA vs ST), there is an increase in postural sway [24, 26]. We postulate that the FA did not exhibit improvements over time as there may have been a ceiling effect in performance, due to the simplicity of the task. For instance, the ST task was more difficult and allowed for improvement in performance over time.

Reaction time

The present findings revealed no significant changes in SRT over time. However, significant improvements in CRT were found such that average CRT and within-subject SD of CRT progressively improved across the 5 sessions. More specifically, there was a 17.2% improvement in average CRT and a 42.1% improvement in the within-subject SD of CRT between sessions 1 and 5, as shown in Figures 1 and 2, respectively. That is, participants not only gradually improved in their raw average score of CRT, but they were also more consistent in their RTs, which emphasizes practice-induced gains in cognitive plasticity. Importantly, we found high effect sizes for both the average ($\eta^2=0.431$) and within-subject SD ($\eta^2=0.431$) of CRT

over time, which underlines the robustness of these pilot data [29]. Altogether, the current study shows more suggestive evidence towards cognitive plasticity in complex compared to simple tasks.

In general, previous work has found improvements in performance of cognitive-motor tasks mainly between the first and second testing sessions after repeated exposure. For example, previous research that repeated the testing session 4 times in one day found a significant improvement between the first and second testing sessions on a battery of cognitive-motor tasks in young and older adults; however, no further improvements were shown over the subsequent sessions [7, 8]. These findings are also consistent with past work [19, 20]. The present study exposed a plateau in average CRT after the second session as there was a significant difference between session 1 compared to sessions 3, 4, and 5. One possible explanation for these differences could be that the present study involved dual-tasking; consequently participants may have required two testing sessions in order to reach optimal performance compared to previous literature that showed a plateau in performance after one session whilst employing a single task model involving seated cognitive-motor tasks [7]. In addition, since this study included older adult participants, they may have required two testing sessions instead of one in order to reach a plateau in performance compared to previous work that showed a plateau after one session in young adults [20]. Notably, we found that the within-subject SD of CRT continued to improve over time, which suggests that participants were able to consistently perform at their optimal level at session 5 compared to sessions 1-4.

The practice-related reductions in RT variability shown in this study are consistent with previous work in older adults [23, 30]. Indeed, there is direct empirical evidence for the shortening of response selection stages as a result of single- and dual-task practice in young

adults [31, 32]. In fact, previous research has shown that older adults do not exhibit a plateau in average RT after 8 sessions [9] and even after 21 sessions [10], or in SD RT after 4 sessions [30], or even 7 sessions [23], which may suggest that they are capable of substantial cognitive learning, but it may also suggest that they require a large amount of practice before reaching their latent reserve capacity. Strobach et al. further suggest that dual-task costs were initially increased in older adults compared to young adults, but the older adults exhibited similar dual-task costs as young adults after practice in some of the conditions [10]. However, the older adults received double the amount of training as the young adults, and the training was adapted such that the conditions were simpler, which resulted in similar dual- and single-task costs. Similarly, because older adults typically exhibit unpracticed and inefficient performance during the first testing session, Strobach et al. (2015) suggest that session 1 should not be used as a proxy to predict practice-related changes over time [23]. Additionally, this study supports that notion that greater initial variability in RT is beneficial for the improvement in dual-task performance over time [30]. Therefore, the lack of a plateau in variability exhibited in the current study suggests that healthy older adults continue to show improvement after repeated testing procedures due to plasticity in cognitive functioning. There are mixed findings with respect to the benefits of practice for SRT tasks. The current study supports the notion for a lack of differences in SRT over time, which is consistent with previous work that examined SRT after 4 weeks of computerized balance training in healthy older adults compared to a control group [22]. However, other research has found significant improvements in SRT after virtual reality or biofeedback training, but these findings may not reveal the repeated effects of testing as the researchers did not include a control group [16]. Other work has exhibited significant improvements in SRT after computerized balance training compared to a control group [33].

Curiously, one study found that one participant exhibited highly optimized dual-task performance during two CRT tasks with no dual-task interference over time, whereas the rest of the participants, gradually improved with practice, which highlights the large between-subject variability [31]. The discrepancy in these findings may be a function of individual differences, ceiling effects in performance, varying task types, different practice schedules, and different practice lengths [16, 22, 31, 33].

We also found that as RT complexity increased, longer RT latencies were exposed. Previous work has delineated that CRT requires the additional executive function of response selection, and this response uncertainty leads to longer RT [34]. In fact, response selection can be accomplished before the onset of the stimulus during SRT because the required response is specified in advance. Because of this preprogramming, the time required for programming is much shorter for SRT compared to CRT [34]. Similar work has shown that practicing a hand CRT task improves response selection and implementation processes, thereby decreasing the response interference effect [35]. In line with the present results, research has shown that practice effects emerge over time with repeated exposure to more difficult tasks compared to simple tasks [8]. Due to a potential ceiling effect in performance, the SRT task did not display improvements over time. It is evident that the dual-task interference effect was more pronounced during the first compared to last testing session, as the difference in average and within-subject variability of RT between CRT and SRT decreased over time. Subsequently, perhaps task coordination skills improved during CRT over time, as previous work has demonstrated such improvements in dual-task contexts, and these practice-specific skills have been shown to transfer to other tasks [36]. Consistent with previous work conducted in our laboratory in young adults [24], when the complexity of the RT task increased, both the postural and RT task were competing for resources

which resulted in slower RT, but no change in COP measures. However, the difference in RT between SRT and CRT was much smaller when comparing session 5 to session 1. Therefore, it is probable that as participants became more acclimated to the CRT task over time, their ability to accurately discriminate between the beeps improved, thereby augmenting performance.

CONCLUSION

The results of this study may serve as a basis to interpret whether clinically relevant changes have emerged after repeated testing procedures that are typically used for intervention experiments. Importantly, we found that there were no changes in COP measures due to repeated exposure to the testing protocol; thus we speculate that improvements exhibited from an intervention can be interpreted as actual improvements because there were no repeated testing effects on posture. Furthermore, we found a plateau in average CRT after the second testing session, but no plateau in CRT variability after 5 testing sessions. Accordingly, researchers and clinicians should take precaution when interpreting repeated testing procedures involving cognitive tasks as it is difficult to ascertain whether improvements in performance were a result of the intervention or repeated testing procedure. An increased emphasis on methodological aspects in relation to RT measures in older adults should be considered in order to correctly interpret findings appropriately as more complex secondary tasks appear to be susceptible to practice effects in a dual-task setting.

COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of potential conflicts of interest

The authors declare that they have no conflict of interest.

Research involving human participants

All procedures performed in studies involving human participants were in accordance with the University of Ottawa Research Ethics Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all participants included in this study.

ACKNOWLEDGEMENTS

This project was financed by an internal grant from the University of Ottawa.

REFERENCES

- [1] Holliday PJ, Fernie GR (1979) Changes in the measurement of postural sway resulting from repeated testing. *Agressologie* 20:225-228.
- [2] Nordahl SH, Aasen T, Dyrkorn BM, Eidsvik S, Molvaer OI (2000) Static stabilometry and repeated testing in a normal population. *Aviat Space Environ Med* 71:889-893.
- [3] Diamanatopoulos II, Clifford E, Birchall JP (2003) Short-term learning effects of practice during the performance of the tandem romberg test. *Clin Otolaryngol* 28:308-313.
- [4] Elliot C, Murray A (1998) Repeatability of body sway measurements; day-to-day variation measured by sway magnetometry. *Physiol Meas* 19:159-164.
- [5] Geurts ACH, Nienhuis B, Mulder TW (1993) Intrasubject variability of selected force platform parameters in the quantification of postural control. *Arch Phys Med Rehabil* 74:1444-1450.
- [6] Black FO, Wall C, Rockette HE, Kitch R (1982) Normal subject postural sway during the Romberg test. *Am J Otolaryngol* 3:309-318.
- [7] Collie A, Maruff P, Darby DG, Mcstephen M (2003) The effects of practice on the cognitive test performance, of neurologically normal individuals assessed at brief test–retest intervals. *Journal of the J Int Neuropsychol Soc* 9:419–428.
- [8] Falleti MG, Maruff P, Collie A, Darby DG (2006) Practice effects associated with the repeated assessment of cognitive function using the CogState battery at 10-minute, one week and one month test-retest intervals. *J Clin Exp Neuropsychol* 28:1095-1112.
- [9] Stobach T, Frensch P, Hermann M, Schubert T (2012) Age- and practice-related influences on dual-task costs and compensation mechanisms under optimal conditions of dual-task performance. *Aging Neuropsychol C* 19:222-247.
- [10] Stobach T, Frensch P, Hermann M, Schubert T (2012) Testing the limits of optimizing dual-task performance in younger and older adults. *Frontiers Hum Neurosci* 6:39:1-12.
- [11] Ruthruff E, Johnston JC, Van Selst MA (2001) Why practice reduces dual-task interference. *J Exp Psychol Human* 27:3–21.
- [12] Kueider AM, Parisi JM, Gross AL, Rebok GW (2012) Computerized cognitive training with older adults: A systematic review *PLoS One* 7(7):e40588.
- [13] Wadley VG, Benz RL, Ball KK, Roenker DL, Edwards JD, Vance DE (2006) Development and evaluation of home-based speed-of-processing training for older adults. *Arch Phys Med Rehabil* 7(6): 757–763.

- [14] Edwards JD, Wadley VG, Meyers RS, Roenker DR, Cissell GM, Ball KK (2002) Transfer of a speed of processing intervention to near and far cognitive functions. *Gerontology* 48(5):329–340.
- [15] Edwards JD, Wadley VG, Vance DE, Wood K, Roenker DL, Ball KK (2005) The impact of speed of processing training on cognitive and everyday performance. *Aging Ment Health* 9(3): 262–271.
- [16] Bisson E, Contant B, Sveistrup H, Lajoie Y (2007) Functional balance and dual-task reaction times in older adults are improved by virtual reality and biofeedback training. *Cyberpsychol Behav* 10(1):16–23.
- [17] Jamieson BA, Rogers WA (2000) Age-related effects of blocked and random practice schedules on learning a new technology. *J Gerontol B Psychol Sci Soc Sci* 55B(6):P343.
- [18] Cassavaugh ND, Kramer AF (2009) Transfer of computer-based training to simulated driving in older adults. *Appl Ergon* 40:943–952.
- [19] Eckner JT, Kutcher JS, Richardson JK (2011) Between-seasons test-retest reliability of clinically measured reaction time in National Collegiate Athletic Association Division I athletes. *J Athl Train* 46:409–414.
- [20] Del Rossi G, Malaguti A, Del Rossi S (2014) Practice effects associated with repeated assessment of a clinical test of reaction time. *J Athl Train* 49:356-359. doi:10.4085/1062-6059-49.2.04.
- [21] Howe TE, Rochester L, Neil F, Skelton DA, Ballinger C (2011) Exercise for improving balance in older people. *Cochrane Db Syst Rev* 11:CD004963.
- [22] Hinman MR (2002) Comparison of two short-term balance training programs for community-dwelling older adults. *J Geriatr Phys Ther* 25(3):10–20.
- [23] Strobach T, Gerstorf D, Maquestiaux F, Schubert T (2015) Does initial performance variability predict dual-task optimization with practice in younger and older adults? *Exp Aging Res* 41:57–88.
- [24] Jehu DA, Despons A, Paquet N, Lajoie Y (2015) Prioritizing attention on a reaction time task improves postural control and reaction time. *Int J Neurosci* 125:100-106.
- [25] Winter DA, Eng P (1995) Human balance and posture control during standing and walking. *Gait Posture* 3:193-214.
- [26] Remaud A, Boyas S, Lajoie Y, Bilodeau M (2012) Attentional focus influences postural control and reaction time performances only during challenging dual-task conditions in healthy young adults. *Exp Brain Res* 231:219-229.

- [27] Wallmann HW, Gillis CB, Alpert PT, Miller SK (2009) The effect of a senior jazz dance class on static balance in healthy women over 50 years of age: a pilot study. *Biol Res Nurs* 10:257-266.
- [28] Weerdesteyn V, Rijken H, Geurts AC, Smits-Engelsman BC, Mulder T, Duysens J (2006) A five-week exercise program can reduce falls and improve obstacle avoidance in the elderly. *Gerontology* 52:131-141.
- [29] Cohen J (1988) *Statistical power analysis for the behavioral sciences*. second ed., Hillsdale, New Jersey, Erlbaum.
- [30] West R, Murphy KJ, Armilio ML, Craik FI, Stuss DT (2002) Lapses of intention and performance variability reveal age-related increases in fluctuations of executive control. *Brain Cogn* 49(3):402-419.
- [31] Ruthruff E, Johnston JC, Van Selst M, Whitsell S, Remington R (2003) Vanishing dual-task interference after practice: Has the bottleneck been eliminated or is it merely latent? *J Exp Psychol Human* 29(2):280–289 .
- [32] Strobach T, Liepelt R, Pashler H, Frensch PA, Schubert T (2013) Effects of extensive dual-task practice on processing stages in simultaneous choice tasks. *Atten Percept Psychophys* 75(5):900-20.
- [33] Lajoie Y (2004) Effect of computerized feedback postural training on posture and attentional demands in older adults. *Aging Clin Exp Res* 16(5):363–368.
- [34] Klapp ST, Rodriguez G (1982) Programming time as a function of response duration: A replication of ‘dit–dah’ without possible guessing artifacts. *J Motor Behav* 14:46–56.
- [35] Hart MA, Reeve R (2002) Influence of practice on response-selection and response-implementation processes involved in the response-interference effect. *Acta Psychologica* 109:177-194.
- [36] Strobach T, Frensch PA, Soutschek A, Schubert T (2012) Investigation on the improvement and transfer of dual-task coordination skills. *Psychol Res* 76(6):794–811.

CHAPTER 4: STUDY 2

Improvements in obstacle clearance parameters and reaction time over a series of obstacles revealed after 5 repeated testing sessions in older adults

This article is in review in Motor Control,
and has been formatted accordingly. Both Drs. Yves Lajoie
and Nicole Paquet give their consent to the inclusion of this
manuscript in the current dissertation.

Deborah A. Jehu¹, Yves Lajoie¹, Nicole Paquet^{2*}

1. University of Ottawa, School of Human Kinetics, Ottawa, ON
2. University of Ottawa, School of Rehabilitation Sciences, Ottawa, ON

*Corresponding Author Information:

Nicole Paquet, PhD.

School of Rehabilitation Sciences

University of Ottawa

451 Smyth Road, Ottawa ON Canada, K1N6N5

Phone: 613-562-5800 ext. 8039

Fax: 613-562-5428

Email: npaquet@uottawa.ca

Date of manuscript submission: September 27, 2016

Date of first revision: January 29, 2017

Date of second revision: July 1, 2017

Running head: Dual-task obstacle clearance in older adults

Abstract

The purpose was to investigate obstacle clearance and reaction time (RT) parameters when crossing a series of 6 obstacles in older adults. A second aim was to examine the repeated exposure of this testing protocol once per week for 5 weeks. Ten older adults (5 females; age: 67.0 ± 6.9 years) walked onto and over 6 obstacles of varying heights (range: 100-200mm) while completing no RT, simple reaction time (SRT), and choice reaction time (CRT) tasks once per week for 5 weeks. The highest obstacles elicited the lowest toe clearance, and the first three obstacles revealed smaller heel clearance compared to the last three obstacles. Dual-tasking negatively impacted obstacle clearance parameters when information processing demands were high. Longer and less consistent time to completion was observed in session 1 compared to sessions 2-5. Finally, improvements in SRT were displayed after session 2, but CRT gradually improved and did not reach a plateau after repeated testing.

Keywords: obstacle clearance; reaction time; repeated testing; older adults

Introduction

Tripping has been suggested to be one of the main causes of falls in older adults (Berg, Alessio, Mills, & Tong, 1997), with the majority of trips occurring during obstacle negotiation (Overstall, Exton-Smith, Imms, & Johnson, 1977) and in a dual-task context (Tideiksaar, 1996). Older adults tend to adopt a risky obstacle crossing strategy when crossing one or two obstacles by reducing step velocity, step length, step width, coupled with placing the heel closer to the trailing edge of the obstacle compared to young adults (Lowrey, Watson, Vallis, 2007; McFadyen & Prince 2002). However, the obstacle crossing strategies employed during the negotiation of a series of obstacles and the associated attentional requirements in the aging population have not been explored. Therefore, this study examined whether stepping onto a series of obstacles with the dominant foot while avoiding the obstacles with the non-dominant foot once per week for 5 weeks would influence obstacle clearance and reaction time (RT) parameters in older adults.

A wealth of research has examined the influence of stepping over one obstacle (e.g., Chou, & Draganich, 1998; Rhea & Rietdyk, 2007), stepping over two successive obstacles of identical heights (e.g., Berard & Vallis, 2006; Krell & Patla, 2002; Lowrey et al., 2007), as well as stepping over two successive obstacles of varying heights within a trial (e.g., Chen, Ashton-Miller, Alexander, & Schultz, 1991; Harley, Wilkie, & Wann, 2009; Patla & Rietdyk, 1993). Negotiating two obstacles seems to be more attention demanding than crossing one obstacle. For example, Berard and Vallis (2006) found that healthy young adults adopted the same lead toe clearances when crossing one or two obstacles of identical heights, but modulated their crossing strategy when negotiating the second obstacle by reducing the trailing toe clearance. Conversely, similar clearance values as well as similar take-off and landing distances were employed when

negotiating one or two obstacles of identical heights in a travel path in both young and older adults (Lowrey et al., 2007). Precise and consistent foot placement becomes more challenging as the obstacle height increases. In fact, the trajectory of the leading limb has been suggested to be substantially modulated for obstacle height, and minimally for obstacle width (Chen et al., 1991; Patla & Rietdyk, 1993). Indeed, no previous research has explored the role of stepping onto and over obstacles, or negotiating more than two obstacles; however, this is a common activity of daily living.

The attention requirements during one and two obstacle crossings have been examined in the older population (Brown, McKenzie, & Doan, 2005; Chen et al., 1996; Harley et al., 2009; Kim & Brunt, 2007; Schrodt, Mercer, Giuliani, & Hartman, 2004; Siu, Lugade, Chou, van Donkelaar, & Woollacott, 2008). Stepping control during dual-task obstacle clearance seems to be impaired as aging has been associated with greater obstacle contacts (Chen et al., 1996). Reduced gait speed, longer strides, and wider steps during dual-task obstacle crossing have been characteristic of older relative to young adults (Siu et al., 2008). Similarly, increased RT, stepping time, and reduced toe clearance have been observed in older adults (Kim & Brunt, 2007). Kim and Brunt (2007) also highlighted that an increase in the complexity of the dual-task affected performance. That is, as the RT task became more difficult during obstacle crossing, older adults elicited a decrease in toe clearance, as well as an increase in RT and stepping time. Other work has exposed minimal effects on obstacle clearance parameters in a dual-task context, but a decrement in cognitive task performance (Schrodt et al., 2004). Altogether, the compromised dual-task and/or obstacle clearance parameters during obstacle crossing convey that obstacle negotiation stresses the availability of cognitive resources (Brown et al., 2005). A better understanding of the attention requirements when negotiating a series of obstacles may

provide a better identification of deficits and risks associated with obstacle negotiation in the older population.

In addition to understanding the attention and obstacle clearance requirements during the negotiation of a series of obstacles, it is also important to understand whether the repeated exposure to this type of protocol results in performance alterations. Interventions to promote stability during walking have specifically targeted the improvement of obstacle clearance and have shown success in the older adult population (Lamoureux, Sparrow, Murphy, & Newton, 2003); however it is unknown whether these improvements are a product of training or learning effects due to repeated exposure to the testing protocol (e.g., baseline, post treatment, follow-up). Test-retest reliability estimates have been reported to vary for different gait parameters (Lord Howe, Greenland, Simpson, & Rochester, 2011). For instance, one study found that intra-class correlation coefficient values for toe clearance were greater within one testing session (0.98) than those between 4 testing sessions (0.92) during overground walking (Karst, Hageman, Jones, & Bunner, 1999). Other research demonstrated that dual-task practice between the experimental protocol in sessions 1 and 2 resulted in reduced variability of gait velocity, obstacle clearance, and takeoff distance, as well as faster Stroop responses relative to the single-task practice group who received seated cognitive training or the control group in young adults (Worden & Vallis, 2014). This suggests that additional dual-task practice may improve obstacle clearance and cognitive performance. Similarly, prior work has identified a significant difference in targeted foot placement when crossing an obstacle between sessions 1 and 2 in frail older adults (Pichierri, Diener, Muer, & de Bruin, 2013); further indicating that repeated testing may modulate gait and obstacle clearance characteristics.

On the other hand, several studies have examined the repeated administration of cognitive-motor tasks and exposed significant improvements in computerized cognitive-motor testing in young and older adults only within the first two testing sessions, with no further improvements shown across subsequent testing sessions (Collie, Maruff, Darby, & McStephen, 2003; Falletti, Maruff, Collie, & Darby, 2006). Conversely, studies that trained visual and auditory RT tasks in older adults have presented steady improvements throughout the training sessions, without reaching a plateau in performance after 8 (Stobach, Frensch, Hermann, & Schubert, 2012a) and 21 sessions (Stobach, Frensch, Hermann, & Schubert, 2012b). In our recent research, we investigated the stability of simple reaction time (SRT) and choice reaction time (CRT) tasks while standing on a force platform over 5 sessions in older adults (Jehu, Paquet, & Lajoie, 2016). Results demonstrated no significant progression in SRT tasks over time, but CRT gradually decreased such that no plateau in performance was exhibited after 5 testing sessions. These observations suggest that difficult cognitive tasks may require additional testing sessions before reaching maximum performance potential.

The purpose of this study was to compare the effects of obstacle height, obstacle order, and RT difficulty on obstacle clearance and RT parameters when negotiating a series of obstacles in older adults. The second main objective was to examine the influence of the serial administration of the same dual-task obstacle clearance testing protocol once per week for 5 weeks in older adults. Given that the attention capacity framework suggests that performance deteriorations may occur in neither, either, or both tasks (Kahneman, 1973), we hypothesized that if attention demands were high during dual-tasking, obstacle clearance and/or RT parameters would deteriorate and variability would increase compared to single tasking, whereas if attention demands were not exceeded during dual-tasking and automaticity was employed, no change in

obstacle clearance or RT parameters would occur. In addition, we hypothesized that SRT would have a stable performance after repeated exposure due to its potential ceiling effect, but CRT would show an improvement across testing sessions (Jehu et al., 2016). Lastly, we presumed that obstacle clearance would decrease as the height of the obstacle increased (Chou & Draganich, 1998), and that RT would not affect clearance parameters (Brown et al., 2005).

Methods

Participants

Ten healthy older adults (5 males and 5 females; age: 67.0 ± 6.9 years; weight: 75.9 ± 11.8 kg; height: 172.2 ± 9.4 cm) were recruited for this study. Inclusion criteria consisted of: 1) older adults aged 60 years and older; 2) having no self-reported musculoskeletal, neurological or sensory deficits that may affect balance; 3) taking no medications that may affect balance; 4) having no falls with no obvious reason; 5) having normal or corrected to normal vision; 6) living independently in the community; 7) walking without an assistive device; 8) obtaining 24 or greater on the Mini Mental State Exam (MMSE); and 9) and being able to discriminate between high and low pitched auditory beeps.

Procedure

Participants began the testing session by reading and signing the informed consent form approved by the University of Ottawa Research Ethics Board. During the first session, participants completed a demographic questionnaire (i.e. age, sex, and history of disease), and the MMSE. Given that we did not find a protocol that met the criteria of walking onto and over a series of obstacles of varying heights while receiving auditory stimuli, we developed the current novel procedure in which participants negotiated a series of 6 obstacles of small, medium and large heights arranged in a varied order. Participants began with their feet shoulder width apart,

took the first step with their self-selected non-dominant leg, and then stepped onto the first obstacle with their dominant foot, which was set to a fixed 67 cm. Across all experimental conditions, participants were asked to walk at a comfortable pace onto each of the 6 obstacles of varying heights with their dominant foot, and step over to avoid the obstacles with their non-dominant foot. Nine participants chose to step onto the obstacle with their right foot, and 1 with their left. The obstacles were 770 mm in length and 290 mm in width. The height of the obstacles varied such that each succeeding obstacle corresponded to a different height from the previous in order to dampen the likelihood of participants adopting an automatic gait pattern, as follows: 100 mm (obstacle 1), 200 mm (obstacle 2), 150 mm (obstacle 3), 200 mm (obstacle 4), 150 mm (obstacle 5), and 200 mm (obstacle 6; Figure 1). Aerobic steppers, which are commonly used in cardiovascular fitness classes, were employed as the obstacles, and one, two, and three risers were utilized, corresponding to the 100 mm, 150 mm, and 200 mm heights. A foot-switch was placed onto each of the obstacles, and was used to trigger the auditory stimuli. The first step did not have a functional switch as we only had 5 possible ports; however, a mock switch was placed on the first obstacle in order to lead participants to believe that dual-tasking was possible on any obstacle, as such, participants likely adopted a similar crossing strategy across all obstacles. Participants self-selected whether the obstacles would be spaced at a small (460 mm), medium (690 mm), or large (920 mm) distance apart by attempting the various distances and selecting the most comfortable. Two participants chose the small, 6 participants chose the medium, and 2 participants chose the large distance between obstacles. The exact walking path was 5490 mm for the small, 6870 mm for the medium, and 8250 mm for the large distance between obstacles. All participants took 14 steps.

Fourteen reflective markers were placed on both sides of participant on the acromion process, anterior-superior iliac spine, posterior-superior iliac spine, lateral epicondyle, calcaneus, lateral malleolus, and tip of the hallux. The time to completion of stepping onto and over the 6 obstacles was measured from the onset of movement during feet apart to two steps after the last obstacle. Minimum foot clearance was calculated by taking the minimum vertical distance between the dominant toe as well as the swing toe leading up to the anterior side of the obstacle, as well as the minimum distance between the trailing swing heel and the posterior side of the obstacle. A marker was placed on the anterior and posterior edges of each obstacle, and was used to calculate clearance. An estimate of the displacement of the pelvis center of mass in the medial-lateral direction (displacement of the pelvis ML-COM) was calculated by averaging the medial-lateral displacement of the anterior and posterior superior iliac spine on the left and right sides. Obstacle crossing speed was calculated by dividing the distance between each obstacle over time, the distance between the starting point and the first obstacle over time, and the distance between the last obstacle and two steps after over time. None of the participants tripped during the experimental protocol.

Participants were asked to walk onto and over the obstacles while completing no RT, SRT, and CRT tasks. Probe RT protocols have been used to explore attention demand during postural (Jehu, Despons, Paquet, & Lajoie, 2015) and walking tasks (Lajoie, Jehu, Richer, & Tran, 2016). A probe RT protocol was employed, such that auditory stimuli were randomly presented upon foot strike of the dominant foot on the foot-switches placed on each obstacle, in order to present the stimuli at a consistent location. Therefore, all auditory stimuli were administered during double-leg stance. During the SRT trials, participants were asked to verbally respond “tie” to high pitched auditory cues that were randomly administered throughout the

trials. Between 1 and 4 stimuli were presented per trial. During the CRT trials, participants were presented with random high and low auditory stimuli and were asked to respond “tie” and “tow”, respectively. These words were chosen as they have a hard consonant and they also resemble the words “high” and “low”, which were the two different pitches used. Between 2 and 4 stimuli were administered per trial. If participants incurred one or more errors of omission or commission in a single trial, the trial was repeated. On average, participants made 5.00 ± 3.28 , 4.30 ± 2.36 , 4.70 ± 2.45 , 3.80 ± 3.08 , and 2.50 ± 1.58 errors during sessions 1-5, respectively. In total, 17 experimental trials were completed per session including: 3 control trials (i.e., no RT), 6 SRT, and 8 CRT. Prior to the experimental conditions, a familiarization period was performed including 3 seated SRT and CRT 30 s trials as well as 1 trial of walking over the obstacles without auditory stimuli at the beginning of each of the 5 testing sessions conducted across 5 weeks.

Data and statistical analyses

A 3D 8-camera Vicon 512 motion analysis system (Oxford Metrics, Tustin, CA, USA) was used to capture the position of the markers at a sampling frequency of 200 Hz. Kinematic data were analyzed to obtain toe and heel clearance over each obstacle, displacement of the pelvis ML-COM, and time to completion.

An mp3 recorder (Sony MP3 IC Recorder (ICD-UX70), San Diego, CA) was attached to the participants' left arm and used to capture both the high and low auditory stimuli emitted by a piezoelectric speaker and the verbal responses in order to determine RT. The high-pitched signal was administered at a fixed frequency of 2850 Hz whereas the low-pitched signal was administered at a fixed frequency of 970 Hz for approximately 100 ms. The Audacity software system was used

to process RT, which was computed manually through visual inspection using vertical cursors from the start of the verbal response minus the onset of the auditory cue in seconds.

To address whether obstacle height and/or order influenced foot clearance, separate one-way analyses of variance (ANOVAs) were performed on Obstacle (1 to 6) with repeated measures on the mean and standard deviation (SD) of the leading toe of the swing leg, mean and SD of the leading toe of the dominant leg, and the mean and SD of the trailing heel of the swing leg. In order to determine whether dual-tasking and the level of difficulty of the RT task would have an effect on obstacle clearance parameters, separate one-way ANOVAs were performed on RT difficulty (no RT, SRT, CRT) with repeated measures on each factor for the mean and SD of the leading toe of the swing leg, mean and SD of the leading toe of the dominant leg, mean and SD of the trailing heel of the swing leg, mean and SD of the time to completion of the series of 6 obstacles, and mean and SD of the displacement of the pelvis ML-COM. In order to determine the stability of the obstacle clearance parameters over time, separate one-way ANOVAs were performed on Testing Session (1 to 5) with repeated measures on each factor for the mean and SD of the leading toe of the swing leg, mean and SD of the leading toe of the dominant leg, mean and SD of the trailing heel of the swing leg, mean and SD of the time to completion of the series of 6 obstacles, mean and SD of the displacement of the pelvis ML-COM, and mean and SD of SRT and CRT. Lastly, a secondary analysis involving a one-way ANOVA of session 1 was performed on Obstacle (1 to 6) with repeated measures on obstacle crossing speed, in order to verify whether speed contributed to changes in obstacle clearance parameters. When applicable, post hoc least significant difference comparisons were performed. If Mauchly's test of Sphericity was violated, the Greenhouse-Geisser correction was performed. Statistical significance was set to $p < 0.05$.

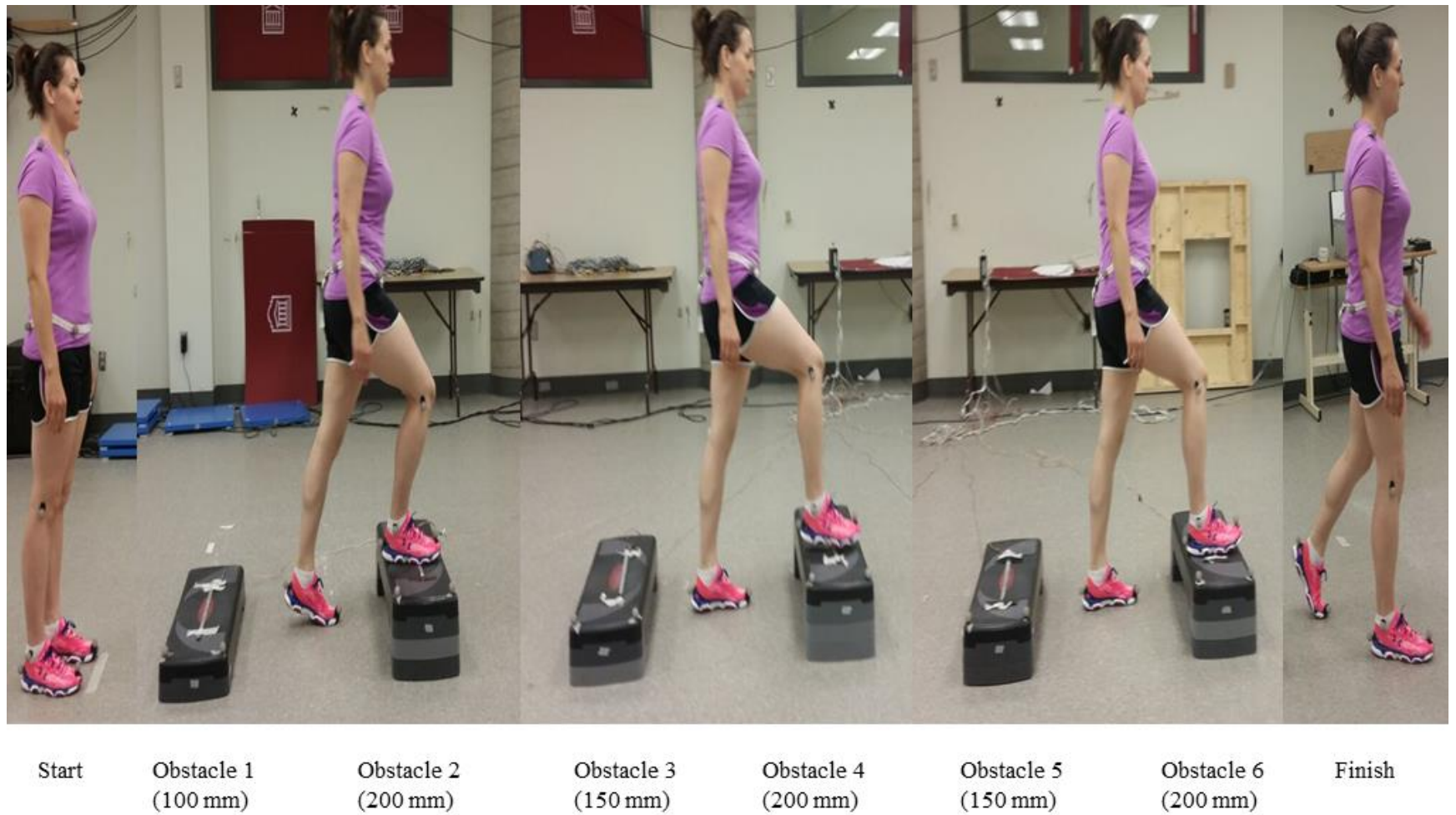


Fig. 1. Diagram of 6 obstacles of varying heights with foot-switches triggering auditory stimuli.

Results

Effect of obstacle height and order on foot clearance

No interaction effects emerged.

A significant main effect of Obstacle was shown for the mean leading toe of the swing leg ($F(5,40)=327.84, p<0.05, \eta^2=0.98$) such that the 100 mm obstacle (obstacle 1) demonstrated significantly greater toe clearance than all of the other obstacles ($p<0.05$; Table 1). The first appearance of the 200 mm obstacle (obstacle 2) showed the least clearance compared to all other obstacles ($p<0.05$; see Figure 1). The first appearance of the 150 mm obstacle (obstacle 3) elicited significantly greater clearance than the second (obstacle 4) and third (obstacle 6) appearance of the 200 mm obstacles ($p<0.05$). The second appearance of the 150 mm obstacle (obstacle 5) had greater clearance than the second (obstacle 4) and third (obstacle 6) appearances of the 200 mm obstacle ($p<0.05$).

A significant main effect of Obstacle was established for the SD of the leading toe of the swing leg ($F(5,40)=3.75, p<0.05, \eta^2=0.35$) such that the first appearance of the 200 mm obstacle displayed a trend for greater variability than the first appearance of the 150 mm obstacle ($p=0.08$), the second appearance of the 200 mm obstacle ($p=0.081$), the second appearance of the 150 mm obstacle ($p<0.05$), and the third appearance of the 200 mm obstacle ($p=0.055$; Table 1). The 100 mm obstacle showed a trend for greater variability than the second occurrence of the 150 mm obstacle ($p=0.07$).

A significant main effect of Obstacle was exposed for the mean leading toe of the dominant leg ($F(5,40)=7.48, p<0.05, \eta^2=0.48$; Table 1). Post hoc analyses revealed that the 100 mm obstacle elicited a trend for greater clearance than the first appearance of the 200 mm obstacle ($p=0.052$) and first appearance of the 150 mm obstacle ($p=0.089$) with significantly

greater clearance than the second and third appearances of the 200 mm obstacles ($p<0.05$).

Additionally, the second appearance of the 150 mm obstacle showed significantly greater clearance than all of the 200 mm obstacles as well as the first appearance of the 150 mm obstacle ($p<0.05$).

A significant main effect of Obstacle was observed for the mean trailing heel of the swing leg ($F(5,40)=5.93$, $p<0.05$, $\eta^2=0.43$; Table 1). The 100 mm obstacle showed significantly less clearance than the second appearance of the 150 mm obstacle as well as the third appearance of the 200 mm obstacle ($p<0.05$). The first appearance of the 200 mm obstacle demonstrated significantly less clearance than the third appearance of 200 mm ($p<0.05$), and a trend for less clearance compared to the second appearance of the 200 mm obstacle ($p<0.064$). Similarly, the first appearance of the 150 mm obstacle presented less clearance than the second and third appearances of the 200 mm obstacles ($p<0.05$). Finally, the third appearance of the 200 mm obstacle showed a trend for greater clearance compared to the second appearance of the 200 mm obstacle ($p=0.059$) and significantly greater clearance compared to the 150 mm obstacle ($p<0.05$).

A significant main effect of Obstacle appeared for the SD of the trailing heel of the swing leg ($F(5,40)=3.21$, $p<0.05$, $\eta^2=0.31$; Table 1). Post hoc analyses revealed that the 100 mm obstacle incurred less variability than the first occurrence of the 150 mm obstacle ($p<0.05$) as well as the third occurrence of the 200 mm obstacle ($p<0.05$). The second occurrence of the 150 mm obstacle showed a trend for less variability than the first occurrence of 150 mm obstacle ($p=0.061$) as well as the third occurrence of the 200 mm obstacle ($p=0.057$).

No significant main effect of Obstacle was shown for the SD of the leading toe of the dominant leg ($F(5,40)=0.46$, $p>0.05$).

A significant main effect of obstacle crossing speed was observed ($F(5,40)=21.23$, $p<0.05$, $\eta^2=0.73$). Post hoc analyses revealed that the first obstacle had a significantly slower speed (i.e., 0.45 m/s) compared to the subsequent obstacles (i.e., 0.80 m/s, 0.88 m/s, 0.86 m/s, 0.85 m/s, 0.85 m/s, for obstacles 2-6, respectively). No differences in speed emerged between obstacles 2-6.

Effect of dual-tasking on obstacle clearance parameters

No interaction effects emerged.

A significant main effect of RT arose for the mean trailing heel of the swing leg ($F(2,18)=11.04$, $p<0.05$, $\eta^2=0.58$; Table 2). Post hoc analyses revealed that no RT elicited greater clearance than SRT and CRT conditions ($p<0.05$). There was also a trend for less clearance for the CRT compared to SRT conditions ($p=0.061$).

A significant main effect for RT was observed for the mean time to completion ($F(2,18)=5.47$, $p<0.05$, $\eta^2=0.41$; Table 2). Post hoc analyses disclosed significantly longer time to completion for the CRT condition compared to no RT ($p<0.05$) and SRT ($p<0.05$).

A significant main effect for RT was observed for the mean displacement of the pelvis ML-COM ($F(2,18)=4.25$, $p<0.05$, $\eta^2=0.35$; Table 2). Post hoc analyses revealed less displacement of the pelvis ML-COM for SRT ($p<0.05$) and CRT ($p<0.05$) compared to no RT conditions.

No main effects of RT were displayed for the mean leading toe of the swing leg ($F(2,18)=0.89$, $p>0.05$), SD of the leading toe of the swing leg ($F(2,18)=0.63$, $p>0.05$), mean leading toe of the dominant leg ($F(2,18)=0.45$, $p>0.05$), SD of the leading toe of the dominant leg ($F(2,18)=1.06$, $p>0.05$), SD of the trailing heel of the swing leg ($F(2,18)=0.76$, $p>0.05$), SD

Table 1
Mean \pm SD of Obstacle Clearance (mm).

	100 mm Obstacle 1	200 mm Obstacle 2	150 mm Obstacle 3	200 mm Obstacle 4	150 mm Obstacle 5	200 mm Obstacle 6
Mean Leading Toe of Swing Leg	223.24 \pm 13.05	59.87 \pm 13.00*	76.20 \pm 8.32*†	66.87 \pm 8.58*†• Θ	81.32 \pm 8.01*†	67.93 \pm 8.61*†• Θ
SD Leading Toe of Swing Leg	13.05 \pm 19.04	13.00 \pm 11.51	8.32 \pm 6.98	8.58 \pm 4.46	8.01 \pm 4.62†	8.61 \pm 3.82
Mean Leading Toe of the Dominant Leg	114.63 \pm 9.19	99.99 \pm 8.66 Θ	102.29 \pm 8.98 Θ	98.99 \pm 9.35* Θ	115.34 \pm 8.44	99.73 \pm 9.89* Θ
SD of the Leading Toe of the Dominant Leg	9.19 \pm 6.34	8.66 \pm 3.73	8.98 \pm 4.37	9.35 \pm 7.25	8.44 \pm 4.46	9.89 \pm 9.06
Mean Trailing Heel of the Swing Leg	98.09 \pm 9.15	99.15 \pm 10.16	98.80 \pm 10.26	104.31 \pm 9.86†•	103.89 \pm 8.88*	114.75 \pm 12.51*• Θ
SD Trailing Heel of the Swing Leg	9.15 \pm 3.48	10.16 \pm 4.84	10.26 \pm 4.81*	9.86 \pm 6.23	8.88 \pm 3.93	12.51 \pm 7.70*

*Represents a significant difference compared to the first appearance of the 100 mm obstacle; † represents a significant difference compared to the first appearance of the 200 mm obstacle; • represents a significant difference compared to the first appearance of the 150 mm obstacle; Θ represents a significant difference compared to the second appearance of the 150 mm obstacle.

Table 2
Effect of RT on Outcome Measures; Mean \pm SD.

	No RT	SRT	CRT
Mean trailing heel of the swing leg (mm)	105.53 \pm 40.76	102.56 \pm 40.20*	101.41 \pm 40.69*
Mean time to Completion (s)	7.60 \pm 0.77†	7.69 \pm 0.90†	7.97 \pm 1.12
Mean COM displacement in the medial-lateral direction (mm)	75.29 \pm 20.24	71.85 \pm 20.03*	70.92 \pm 19.13*

*Represents a significant difference compared to no RT; †represents a significant difference compared to CRT.

of the time to completion ($F(2,18)=1.63, p>0.05$), or SD of the displacement of the pelvis ML-COM ($F(2,18)=0.66, p>0.05$).

Consistency of obstacle clearance parameters over 5 testing sessions

No interaction effects emerged.

A trend for a main effect of Session for the mean trailing heel of the swing leg was shown ($F(4,36)=2.60, p=0.055, \eta^2=0.25$; Table 3). Session 5 provoked a trend for less clearance than sessions 1 ($p=0.072$), 2 ($p<0.05$), and 3 ($p=0.065$).

There was a significant main effect in the mean time to completion ($F(4,36)=7.38, p<0.05, \eta^2=0.48$) over the 5 sessions (Table 3). Post hoc analyses disclosed that session 1 was significantly longer than sessions 2-5.

The significant main effect of Session in the SD of the time to completion ($F(4,36)=4.95, p<0.05, \eta^2=0.38$) revealed that session 1 was significantly more variable than sessions 2-5 ($p<0.05$; Table 3).

No significant differences in Session were shown for the mean leading toe of the swing leg ($F(4,36)=1.22, p>0.05$), SD of the leading toe of the swing leg ($F(4,36)=0.88, p>0.05$), mean leading toe of the dominant leg ($F(4,36)=0.86, p>0.05$), SD leading toe of the dominant leg ($F(4,36)=0.95, p>0.05$), SD of the trailing heel of the swing leg ($F(4,36)=0.52, p>0.05$), mean displacement of the pelvis ML-COM ($F(4,36)=2.54, p>0.05$), or SD of the displacement of the pelvis ML-COM ($F(4,36)=2.36, p>0.05$).

Consistency of RT over 5 testing sessions

No interaction effects emerged.

There was a significant main effect of Session for mean RT ($F(4,36)=17.62, p<0.05, \eta^2=0.69$). Follow-up analyses revealed that SRT was significantly slower during session 1 compared to

Table 3
Effect of Session on Outcome Measures (Mean \pm SD)

	Session 1	Session 2	Session 3	Session 4	Session 5
Mean trailing heel of the swing leg (mm)	108.76 \pm 10.84	110.74 \pm 10.49†	107.78 \pm 9.42	96.91 \pm 9.64	91.64 \pm 10.30
Mean Time to Completion (s)	8.26 \pm 0.43	7.86 \pm 0.27*	7.64 \pm 0.27*	7.57 \pm 0.22*	7.50 \pm 0.26*
SD Time to Completion (s)	0.43 \pm 0.26	0.27 \pm 0.21*	0.27 \pm 0.13*	0.22 \pm 0.13*	0.26 \pm 0.17*

*Represents a significant difference compared to session 1; † represents a significant difference compared to session 5.

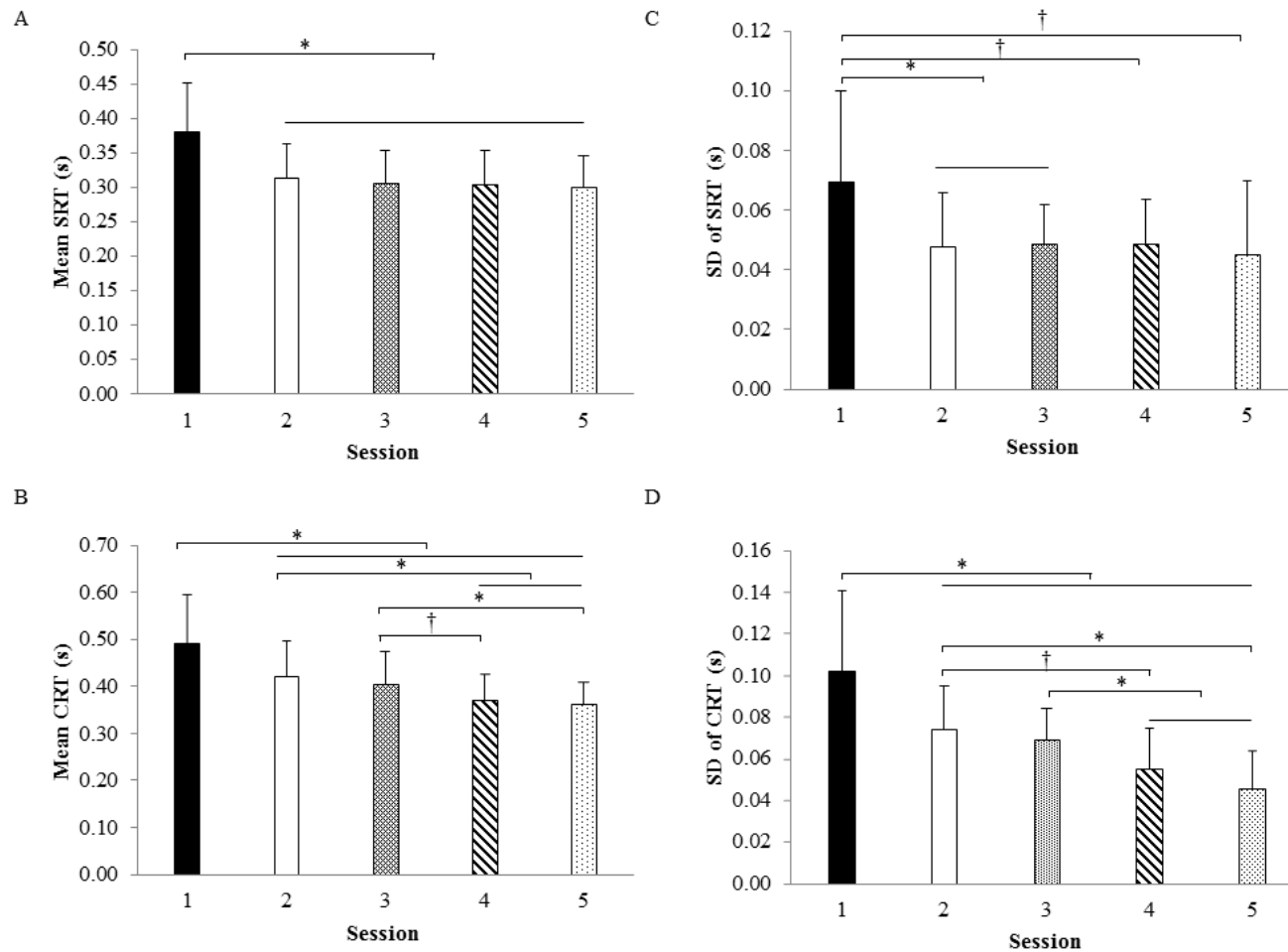


Fig. 2 A. Mean (+ 1 SD) of simple reaction time (SRT) (s); B. Mean (+ 1 SD) of choice reaction time (CRT) (s); C. SD (+ 1 SD) of simple reaction time (SRT) (s); D. SD (+ 1 SD) of choice reaction time (CRT) (s) when walking over 6 obstacles of varying heights over 5 sessions. * $p < 0.05$, † $p < 0.07$

sessions 2-5, session 2 was significantly slower than sessions 4 and 5, and session 3 was significantly slower than session 5 ($p<0.05$), with a trend for longer CRT during session 3 than session 4 ($p=0.054$; Figure 2B).

There was a significant main effect of Session for SD RT ($F(4,36)=11.05$, $p<0.05$, $\eta^2=0.58$). Post-hoc analyses exhibited significantly more variable SRT during session 1 compared to sessions 2 and 3 ($p<0.05$), as well as a trend for more variable SRT between session 1 and 4 ($p=0.063$), and 1 and 5 ($p=0.053$; Figure 2C). CRT was significantly more variable during session 1 compared to sessions 2-5. Session 2 was significantly more variable than session 5 ($p<0.05$), session 2 showed a trend for more variability compared to session 4 ($p=0.064$), and session 3 was more variable than sessions 4 and 5 ($p<0.05$; Figure 2D).

Discussion

This study aimed to discover the influence of obstacle height, obstacle order, and RT difficulty on toe and heel clearance, time to completion, displacement of the pelvis ML-COM, and RT in older adults. We also sought to determine the influence of serial administration of the same testing protocol over 5 weeks on these outcome measures. Notably, we found that 1) toe clearance was reduced for the highest obstacles compared to the lower obstacles, and heel clearance decreased for the first 3 obstacles compared to the last 3 obstacles, 2) completing a SRT or CRT task reduced heel clearance and displacement of the pelvis ML-COM, and completing a CRT task increased the time to completion compared to the no RT condition, 3) the repeated exposure to the testing protocol resulted in reduced heel clearance, as well as faster and less variable time to completion, SRT and CRT. Below we elaborate on each of these findings.

Effect of obstacle height and order on foot clearance

Toe clearance over an obstacle is perhaps the most critical parameter in determining whether tripping will occur. There is evidence to suggest that different proactive locomotor adjustments were employed in the current study such that the dominant foot and non-dominant foot were controlled independently. Because the dominant foot stepped onto the obstacle, while the non-dominant foot stepped over the obstacle, accommodative and avoidance strategies were adopted, respectively (Patla, 1997). Accommodative strategies can involve stepping onto an obstacle while avoidance strategies can involve stepping over to avoid the obstacle (Patla, 1997). In addition, the targeted foot placement of the dominant foot may have been more constraining due to the smaller stepping area, which has been suggested to influence obstacle clearance (Patla, 1997). Despite these fundamental differences between the dominant and non-dominant feet, the current study showed that both the leading and trailing toe clearances were reduced for the highest obstacles likely because higher obstacles increase the challenge to control stability, which is consistent with previous obstacle avoidance work (Chen et al., 1991; Chou & Draganich, 1998; Harley et al., 2009).

No clear pattern for an effect of obstacle order emerged for toe clearance, but smaller heel clearance of the swing leg was shown for obstacles 1-3 relative to obstacles 4-6. Previous research has observed modulations in attention demand during various phases of obstacle clearance, such that during the obstacle crossing, greater dual-task interference emerged compared to pre-crossing (Harley et al., 2009). We extend these findings to suggest that greater information processing demands were involved during the beginning of the negotiation of a series of obstacles, perhaps due to greater motor planning. Our findings underline that both obstacle height and order may contribute to changes in obstacle clearance parameters in older

adults. It is possible that systematically changing the order of the obstacle heights may increase attention demand and modulate obstacle crossing parameters; as such, this could be considered for future research.

No differences in the variability of toe clearance on the height of the obstacle were observed in this study, which is consistent with previous work (Harley et al., 2009). We extend earlier findings to report that neither the height nor the order of the obstacles affected toe clearance variability. Furthermore, less heel clearance was shown for the first three obstacles compared to the last three obstacles. Obstacle clearance occurred very rapidly following gait initiation, which has been delineated to pose a challenge to the postural control system due to the volitional transition from a condition of static, stable support to continuously unstable during obstacle negotiation (Martin et al., 2002). Perhaps the increased instability and greater attention demand required during gait initiation coupled with a lack of steady gait speed during the clearance of the first three obstacles led to reduced heel clearance compared to the last three obstacles.

The first obstacle displayed significantly slower obstacle crossing speed compared to subsequent obstacles. Faster obstacle crossing speeds may result in larger toe-obstacle clearance in older adults (Draganich & Kuo, 2004). In contrast, we found larger clearance for the leading toe of the swing leg for the first obstacle, despite the reduced crossing speed. Perhaps this modulation in crossing strategy was not a function of speed, but rather of obstacle height and order. In addition, we observed that the trailing heel of the swing leg exhibited less clearance and variability over the first obstacle compared to the second appearance of the 150 mm obstacle as well as the third appearance of the 200 mm obstacle. To our knowledge, no previous literature has examined the influence of obstacle crossing speed on heel clearance; it is therefore possible

that speed was a factor in the obstacle crossing strategy. Slower walking speed has been detected to lead to greater attention demand (Lajoie, Jehu, Richer, & Tran, 2016), thus speed may have, in part, contributed to differences in obstacle clearance over the first obstacle.

Some research has reported less toe clearance (Chou & Draganich, 1998), whereas other work has outlined greater toe clearance (Chen et al., 1991) over higher obstacles compared to lower obstacles. The present toe clearances seem to be generally smaller compared to previous research including one obstacle clearance task, with toe clearances ranging between approximately 123-160 mm for obstacle heights ranging from 25-204 mm (Chou & Draganich, 1998; Harley et al., 2009). These differences in toe clearance may be a function of differences in experimental design and/or the obstacle negotiation strategy employed. Perhaps negotiating a series of obstacles may elicit reduced toe clearance due to greater information processing demands. Overall, our findings suggest that the risk for toe-obstacle contact increases when negotiating higher compared to lower obstacles; and greater postural instability may occur at the beginning of a series of obstacle crossings, as evidenced by reduced heel clearance.

Effect of dual-tasking on obstacle clearance parameters

Completing a dual-task reduced heel clearance as well as increased displacement of the pelvis ML-COM. A longer time to negotiate the series of obstacles was also exposed when performing a difficult dual-task. A large body of research has revealed dual-task interference during obstacle crossing in older adults (Brown et al., 2005; Chen et al., 1996; Harley et al., 2009; Kim & Brunt, 2007; Schrodt et al., 2004; Siu et al., 2008). Some research has reported that cognitive tasks have a destabilizing effect on obstacle negotiation such that participants increased foot clearance variability during a verbal fluency task (Harley et al., 2009), and reduced gait velocity during the Stroop test, leading to longer strides and wider steps (Siu et al., 2008). In

contrast, other research has identified no interference in obstacle clearance parameters during a verbal RT (Brown et al., 2005) or a 1-back task (Schrodt et al., 2004). The current findings conflict with our previous work in quiet standing, which exposed that a reallocation of attention from posture to the RT tasks promoted an automatic and efficient control of posture (Lajoie, Jehu, Richer, & Chan, 2017). However, stepping over several obstacles of varying heights and in close proximity was more challenging and likely demanded greater attention than static postural control as well as crossing only one small obstacle. Our findings suggest that the decrements in obstacle clearance parameters during dual-task conditions may have stemmed from a competition of attention resources and resulted in exceeded attention capacity.

Additionally, the reduced displacement of the pelvis ML-COM observed during the SRT and CRT conditions may be suggestive of a stiffening strategy in order to reduce the degrees of freedom of the center of mass to facilitate successful obstacle clearance during dual-tasking. Reducing the degrees of freedom of the displacement of the pelvis ML-COM may have afforded more attention resources to be allocated to the RT task. During quiet standing, a stiffening strategy has been suggested to be constrained (Carpenter, Frank, Silcher, & Peysar, 2001) due to the elevated co-activation of lower-leg muscles or by a tighter neuromuscular control (or a combination of both; Stins, Roerdink, & Beek, 2011). Stiffening may also be mechanically inefficient due to muscular co-contraction. Moreover, the older participants may have attempted to adopt a cautious obstacle crossing strategy by reducing their walking speed coupled with decreasing their degrees of freedom; however, the competing attentional resources likely resulted in the smaller heel clearance and greater risk for tripping.

Interestingly, toe clearance has been demonstrated to increase with increasing gait speed as a means to reduce trip-risk during over-ground walking and more hazardous gait conditions

such as walking over visible and hidden obstacles in young adults (Schulz, 2011). However, the current older sample incurred no differences in toe-clearance despite the increase in walking speed for the no RT and SRT compared to CRT conditions. Therefore, the marked changes in obstacle clearance parameters during dual-tasking provide further evidence that the increased attention demand may compromise motor performance.

Consistency of obstacle clearance parameters over 5 testing sessions

This is the first study to examine the repeatability of obstacle clearance parameters whilst employing the dual-task paradigm. Interestingly, we found that older adults adopted a more cautious strategy as evidenced by slower and more variable time to completion during the first testing session compared to sessions 2-5. Walking slower during the first session may have provided older adults with more time to target their foot placement on the obstacle, accurately clear the obstacle, as well as plan an appropriate foot clearance on the subsequent obstacles of differing heights. With repeated testing, perhaps participants became more confident and accustomed to the testing environment. It is also possible that practice-induced improvements in the variability of the time to completion resulted in greater efficiency and consistency due to learning.

Consistency of RT over 5 testing sessions

Significant improvements in the mean and variability of SRT were shown between the first session compared to sessions 2-5. In contrast, previous research employing the same SRT task in standing postural control observed no improvements over 5 sessions (Jehu et al., 2016). Presumably, the obstacle negotiation task was much more difficult than standing postural control, and was therefore more sensitive to repeated exposure. Participants did not perform at an optimal level during the first testing session compared to subsequent testing sessions, likely

because the task required greater attention demand and longer time to learn the task. Practice-induced gains in cognitive plasticity have been a hallmark following cognitive and physical training (Bamidis et al., 2015). Improvements in both the mean and SD of RT provides insight into the practice-related changes in the latency of information processing as well as the decreased likelihood to make errors. Thus, the repeated exposure to the SRT task across sessions may suggest that these improvements could be a function of gains in cognitive plasticity. It is equally possible that participants were more comfortable and confident during sessions 2-5, which may also explain the improved RTs.

The present results concur with prior research in that we observed a gradual reduction in the mean and variability of CRT with no plateau in performance after 5 testing sessions (Jehu et al., 2016). The majority of research delineates a plateau in cognitive performance after 1 testing session (Collie et al., 2003; Del Rossi, Malaguti, & Del Rossi, 2014; Eckner, Kutcher, & Richardson, 2011; Falletti et al., 2006); however these studies did not employ a dual-task framework, and therefore may have resulted in accelerated learning. Because CRT is a more difficult task than SRT, it may require a longer practice period in order to achieve optimal performance. Specifically, the use of the words “tie” and “tow” instead of “high” and “low” during the CRT task may have introduced working memory and inhibition processing, as participants were required to not only remember these words, but also inhibit responding with more congruent “high” and “low” words. In comparison, the SRT task was much simpler, as only one response was requisite, thereby involving less working memory and inhibition processing. Altogether, the current study underlines that cognitive plasticity is evidenced in both simple and complex auditory-verbal tasks when negotiating obstacles. The present results therefore suggest that repeated exposure to a testing protocol improves the overall timing and

consistency in processing information. These findings lend to reason that researchers and clinicians should take precaution when interpreting repeated testing procedures involving obstacle clearance and cognitive tasks as it is difficult to ascertain whether improvements in performance are a result of an intervention or repeated testing procedure.

Limitation

The inherent limitation of the dual-task paradigm implicates the inability to ascertain how participants prioritized attention. It is not possible to establish with certainty whether participants prioritized one task over the other within or between sessions.

Conclusion

In conclusion, walking over a series of obstacles of differing heights negatively influenced obstacle clearance and RT parameters when information processing demands were high in older adults. Improvements in obstacle clearance parameters were exhibited after serial administration of the protocol. A plateau in SRT was displayed after session 2, but CRT gradually improved across testing sessions and showed no plateau. Altogether, our findings suggest that obstacle clearance parameters as well as RT are sensitive to early improvement and should therefore be included as outcome measures for therapeutic interventions.

Acknowledgements

This project was financed by an internal grant from the University of Ottawa.

Conflict of interest statement

The authors declare that they have no conflict of interest.

References

- Bamidis, P.D., Fissler, P., Papageorgiou, S., Zilidou, V., Konstantinidis, E.I., Billis, A.S...Kolassa, I.T. (2015). Gains in cognition through combined cognitive and physical training: the role of training dosage and severity of neurocognitive disorder. *Frontiers in Aging Neuroscience*, 7, 152.
- Berard, J.R., & Vallis, L.A. (2006). Characteristics of single and double obstacle avoidance strategies: A comparison between adults and children. *Experimental Brain Research*, 175(1), 21–31.
- Berg, W.P., Alessio, H.M., Mills, E.M., & Tong, C. (1997). Circumstances and consequences of falls in independent community-dwelling older adults. *Age and Ageing*, 26, 261–268.
- Brown, L.A., McKenzie, N.C., & Doan, J.B. (2005). Age-dependent differences in the attentional demands of obstacle negotiation. *Journal of Gerontology Series A: Biological and Medical Sciences*, 60, 924–927.
- Carpenter, M.G., Frank, J.S., Silcher, C.P., & Peysar, G.P. (2001). The influence of postural threat on the control of upright stance. *Experimental Brain Research*, 138, 210–218.
- Chen, H.C., Ashton-Miller, J.A., Alexander, N.B., & Schultz, A.B. (1991). Stepping over obstacles: gait patterns of healthy young and old adults. *Journal of Gerontology Series A: Biological and Medical Sciences*, 46, M196–203.
- Chen, H.C., Schultz, A.B., Ashton-Miller, J.A., Giordani, B., Alexander, N.B., & Guire, K.E. (1996). Stepping over obstacles: dividing attention impairs performance of old more than young adults. *Journal of Gerontology Series A: Biological and Medical Sciences*, 51, M116–122.

- Chou, L., & Draganich, L.F. (1998). Placing the trailing foot closer to an obstacle reduces flexion of the hip, knee, and ankle to increase the risk of tripping. *Journal of Biomechanics*, *31*, 685–691.
- Collie, A., Maruff, P., Darby, D.G., & McStephen, M. (2003). The effects of practice on the cognitive test performance, of neurologically normal individuals assessed at brief test–retest intervals. *Journal of the International Neuropsychological Society*, *9*, 419–428.
- Del Rossi, G., Malaguti, A., & Del Rossi, S. (2014). Practice effects associated with repeated assessment of a clinical test of reaction time. *Journal of Athletic Training*, *49*, 356-359.
- Draganich, L.F., & Kuo, C.E. (2004). The effects of walking speed on obstacle crossing in healthy young and healthy older adults. *Journal of Biomechanics*, *37*, 889-896.
- Eckner, J.T., Kutcher, J.S., & Richardson, J.K. (2011). Between-seasons test-retest reliability of clinically measured reaction time in National Collegiate Athletic Association Division I athletes. *Journal of Athletic Training*, *46*, 409–414.
- Falletti, M.G., Maruff, P., Collie, A., & Darby, D.G. (2006). Practice effects associated with the repeated assessment of cognitive function using the cogstate battery at 10-minute, one week and one month test-retest intervals. *Journal of Clinical and Experimental Neuropsychology*, *28*, 1095-1112.
- Pichierri, G., Diener, T., Murer, K., & De Bruin, E.D. (2013). Assessment of the test-retest reliability of a foot placement accuracy protocol in assisted-living older adults. *Gait & Posture*, *38*(4), 784-789.
- Schulz, D.W. (2011). Minimum toe clearance adaptations to floor surface irregularity and gait speed. *Journal of Biomechanics*, *29*, 1277-1284.

CHAPTER 5: EXPERIMENT 3**Balance and mobility training with or without concurrent cognitive training improves the timed up & go (TUG), TUG cognitive and TUG manual in healthy older adults: An exploratory study**

A version of this article has been published in Aging Clinical and Experimental Research,

and has been formatted accordingly. Both Drs. Yves Lajoie and Nicole Paquet give their consent to the inclusion of this manuscript in the current dissertation.

Deborah A. Jehu^a, Nicole Paquet^{a,b} and Yves Lajoie^a

^a School of Human Kinetics, University of Ottawa, 125, University Avenue, Ottawa, Ontario, K1N 6N5 Canada

^b School of Rehabilitation Sciences, University of Ottawa, 451 Smyth road, Ottawa, Ontario K1H 8M5 Canada.

Corresponding author

Yves Lajoie, PhD.
University of Ottawa, Health Sciences, School of Human Kinetics
125 University St, Ottawa, Ont., Canada, K1N6N5
Phone: +1-613-562-5800 ext. 4273
Fax: (613) 562-5497
Email: ylajoie@uottawa.ca

ABSTRACT. Background and aims: The purpose was to explore the impact of balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and no training on the timed up & go (TUG), TUG cognitive (TUGcog), and TUG manual (TUGman) in older adults. A preliminary study examined the stability of these TUG measures over a 5-week period in older adults. **Methods:** Fifteen participants in the BMT group (70.2 ± 3.2 years) and 14 participants in the BMT+C group (68.7 ± 5.5 years) trained one-on-one, 3x/week for 12 weeks on a balance obstacle course. The BMT group and the BMT+C group completed 2 or 3 tasks simultaneously, respectively. Fifteen participants in the control group received no training (66.7 ± 4.2 years). The TUG, TUGcog, and TUGman were measured in seconds at baseline, after the 12-week training, and after the 12-week follow-up. During the preliminary study, 10 participants (67.0 ± 6.9 years) completed the three TUG measures 1/week for 5 weeks. **Results:** Both the BMT and BMT+C groups, but not the control group, exhibited significantly faster TUG, TUGcog and TUGman after the intervention and maintained these improvements at the 12-week follow-up. No differences between the BMT and BMT+C groups emerged. The preliminary study showed that the three TUG measures were stable across 5 testing sessions. **Discussion and conclusions:** Both training groups improved functional mobility after the interventions and sustained these improvements over 12 weeks. This is likely not a function of repeating the TUG, TUGcog, and TUGman tests since no repeated exposure effect was shown.

Keywords

Balance training, cognitive training, dual-tasking, timed up & go, mobility, aging

INTRODUCTION

Falling is a common occurrence for older adults. One third of older adults aged 65 fall every year, and this increases to one half for older adults at the age of 80 [1]. Declines in physical and cognitive functioning have been identified as intrinsic risk factors for falling [2,3]. The loss of functional mobility can have serious implications for older adults including increased risk for falls, greater dependency on others, diminished quality of life and an increased likelihood of hospital stays [4].

The timed up & go (TUG) is a commonly used functional mobility assessment tool. It is administered by asking the participant to get up from a chair without using arm rests, walk 3 m as quickly as possible without running, turn around, walk back to the chair, and sit down without using arm rests [5]. It has shown excellent test-retest reliability (ICC=0.97) in community-dwelling older adults [6]. Steffen and colleagues (2002) have established normative data for the TUG in community-dwelling older adults [6]. Males and females aged 60-69 are typically able to complete the TUG in 7-9 s, whereas males aged 70-79 are able to complete the TUG between 7-11 s and females of the same age are able to do so in 8-10 s [6]. Normative data for healthy older adults for the TUG cognitive (TUGcog) have been reported to be 9.8 s and 11.6 s for the TUG manual (TUGman) [7]. Additionally, the cut-off score for increased risk of falls has been reported to be greater than 13.5 s on the TUG and greater than 15 s for the TUGcog in community-dwelling older adults [8]. A systematic review of home-based training programs including the TUG as a testing measure has reported clinically relevant improvements in functional mobility with an average decrease in TUG time of -0.8 ± 0.5 s [9].

There have been mixed findings with respect to whether balance training improves functional mobility as measured by the TUG. For example, previous research has shown no

improvements in the TUG (9.6 s to 9.1 s), but significant improvements in the TUGcog (14.1 s to 11.5 s) after an 8-week home-based step training program in healthy older adults [10]. Other research training healthy older adults over the age of 70 on Xbox Kinetic [11] and Nintendo Wii Fit [12] 3 times per week for 3 weeks displayed no improvements in the TUG. However, it is important to note that the majority of experiments have exposed significant improvements in the TUG in older adults after training [9, 13-19]. For instance, one experiment administered strength and balance exercises once per week for 7 weeks and found significant improvements in the TUG (13.5 s to 11.4 s) among 366 older adults with a low- or high-risk risk for falls [18]. Interestingly, one experiment compared the effects of five sessions of cognitive dual-task training including a variety of two-choice visual discrimination tasks with feedback on a computer [17]. Although there were no physical exercises, purely cognitive training resulted in improved gross motor skills including faster walking speed during the 40-foot walk, and reduced sway during one-legged and two-legged stance as well as cognitive tasks in healthy older adults. Similarly, other research has shown further improvements in gait velocity and single support time during fast gait with a concurrent cognitive task in older adults who received strength and balance exercises with the addition of a cognitive-motor dance game compared to older adults who only completed the strength and balance exercises [20]. This literature suggests that the addition of cognitive training to balance training interventions may provoke further improvements in gross motor skills.

However, it is possible that these improvements in functional mobility following training have been shown due to the repeated testing of the TUG. Limited research has examined the repeated administration of the TUG across several sessions. One study examined the repeated exposure to the TUG and found excellent test-retest reliability (ICC=0.960) across 5 consecutive

days [21]. Although excellent test-retest reliability was shown, this study did not compare whether the sessions were significantly different from each other. Previous research has reported clinically relevant improvements in functional mobility have been reported to be -0.8 ± 0.5 s for the TUG in community-dwelling older adults [9]. When comparing the first session to the fifth session, there was a -0.8 s change in on the TUG, -1.3 s in the TUGcog, and -0.5 s in the TUG manual (TUGman) [21]. These differences suggest that significant improvements may be shown across repeated administration.

Since the TUG, TUGcog, and TUGman have been reported to be comparable in determining the likelihood of falls in older adults [8], each of these measures has been included in this experiment. The present experiment is the exploratory phase of a larger experiment to be designed in the future. This randomized-block, not blinded, pilot experiment with a control group was conducted on three small groups (≤ 15 participants) of healthy adults aged between 60 and 77 years old. The overarching purpose was to investigate whether 12 weeks of balance and mobility training (BMT) or 12 weeks of balance and mobility plus cognitive training (BMT+C) would improve the TUG, TUGcog, and TUGman compared to the control group. A second aim was to explore whether further improvements in the TUGcog would be exposed in the BMT+C compared to the BMT groups. Our third objective was to investigate whether possible improvements in the TUG, TUGcog, and TUGman after BMT and BMT+C training would be maintained after a 12-week follow-up period. Our primary hypothesis was that both the BMT and BMT+C groups would demonstrate significantly faster TUG, TUGcog, and TUGman performance compared to the control group. We also hypothesized that the BMT+C group would show additional improvements in the TUGcog compared to the BMT group as previous work has delineated that simply completing computerized cognitive tasks improves functional

performance [17]. Finally, it was hypothesized that both training groups would maintain their improvements in the TUG, TUGcog, and TUGman after a 12-week follow-up compared to the control group, as shown by previous work [22, 23]. Since the TUG, TUGcog, and TUGman are repeated across testing sessions in this study, a preliminary study investigated whether these tests would improve with serial administration once per week for 5 weeks in healthy older adults. It was hypothesized that there would be no significant differences in these tests across the 5 sessions as the TUG has shown excellent test-retest reliability [21].

METHODS

Participants

This experiment was approved by the Research Ethics Board at the University of Ottawa. Participants were recruited via posters, announcements at community activities, and word of mouth. Inclusion criteria consisted of being 60 years of age and older, having no self-reported musculoskeletal, neurological or sensory deficits that may affect balance, having normal or corrected to normal vision, living independently in the community, walking without an assistive device, and obtaining a score of 27 or greater on the Mini-Mental State Examination (MMSE).

Seventy-six individuals were assessed for eligibility. Twenty-eight individuals were excluded, 8 did not meet the eligibility criteria and 20 were not interested. Forty-eight healthy older adults were block-randomized by age to the BMT group (n=17; age range: 65-76 years), the BMT+C group (n=17; age range: 60-77 years), or the control group (n=14; age range: 62-77 years) (Figure 1). Age was used as a blocking factor in order to control for significant deviations in age between groups.

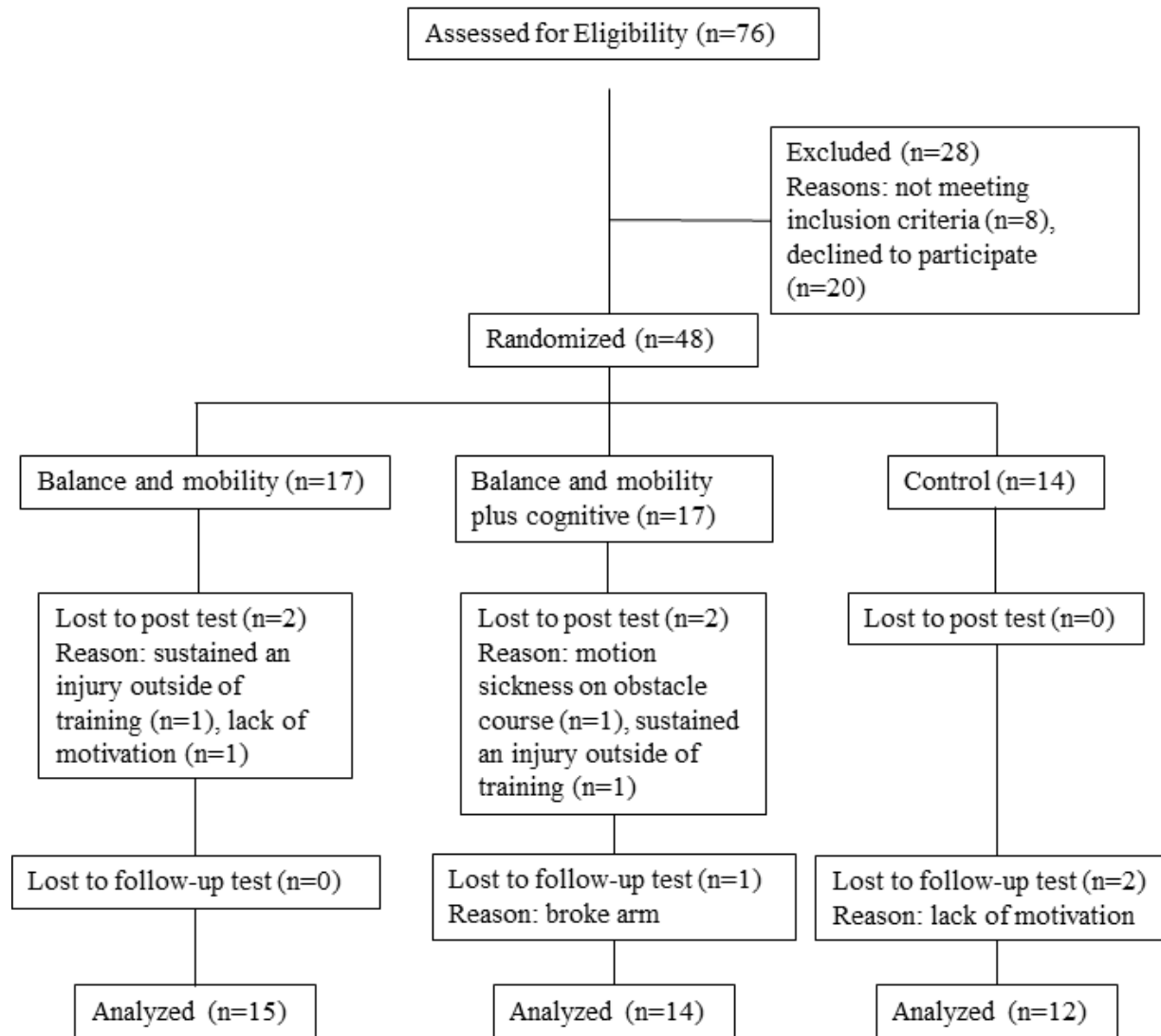


Fig. 1. Flow chart of participant recruitment, adherence and attrition.

Testing protocol

To describe the sample and to rule out other factors that may affect balance, participants completed the following during the first testing session: a demographic questionnaire (i.e., age, sex, education, history of disease, and fall history), the MMSE, the Activity-specific Balance Confidence scale (ABC), and the Godin Leisure-time Physical Activity questionnaire (Godin). The MMSE is an 11-item questionnaire that tests 5 areas of cognitive function: orientation, registration, attention and calculation, recall, and language. Previous work reports that healthy older adults' mean score was 27.6 on the MMSE, which suggests a cut-off for healthy older adults would be less than 27 [24]. The ranges for the MMSE were 28-30 for the BMT group, 29-30 for the BMT+C group, 28-30 for the control group, and 29-30 for the preliminary study group. A fall was defined as an event in which the individual came to rest on the ground or other lower level. The ABC scale is a 16-item questionnaire that assesses the confidence in one's ability to perform 16 daily activities without falling on a scale from 0% (no confidence) to 100% (complete confidence) [25]. The Godin questionnaire assesses weekly frequencies of mild, moderate, and vigorous physical activities performed for at least 15 minutes with the total weighted score calculated in the metabolic equivalent of the task (MET) [26]. The Godin has a correct two-way classification of 69% of the participants [26]. Participants then had height (cm) and weight (kg) taken. Participant characteristics are reported in Table 1.

Next, participants performed three trials of the TUG, TUGcog, and TUGman in a random order at baseline, after the 12-week intervention period, and after a 12-week follow-up. For the control group, testing was conducted three times: at week 1, week 12 and week 24. The TUG was assessed by asking the participants to get up from an armless chair, walk 3 m as quickly as possible without running, turn around, walk back to the chair, and sit down [5]. During the

Table 1. Participant characteristics (Mean \pm SD)

Group	Age (years)	Sex (male/female)	Height (cm)	Weight (kg)	Education (years)
BMT (n=15)	70.2 \pm 3.2	3/12	162.6 \pm 8.9	79.0 \pm 17.9	17.4 \pm 2.8
BMT+C (n=14)	68.7 \pm 5.5	6/ 9	165.5 \pm 10.7	72.7 \pm 16.4	18.0 \pm 2.4
Control (n=12)	66.3 \pm 4.4	3/9	166.3 \pm 9.1	72.5 \pm 13.8	18.5 \pm 2.6

TUGcog, participants completed the same walking task while counting backwards by 3's from a random number between 20 and 100 [8]. The instructions were to “walk as quickly as possible without running while counting as many numbers as possible”. No participant counted backwards to 0 before finishing the TUGcog task. During the TUGman, participants completed the same walking task while carrying a tray with a cup full of water, which is similar to previous work [8]. The instructions were to “walk as quickly as possible without running or spilling the water”. Participants were asked to give equal priority to both tasks. The mean amount of numbers counted during the TUGcog and the number of participants who spilled during the TUGman are reported in Table 2. No familiarization of the TUG tasks was performed. Each of these tasks was timed using a stop watch and an average time in seconds of the three trials was used for analysis.

Intervention

The following training protocol has been developed to meet the aims of a series of experiments pertaining to the impact of cognition added to balance training on several posture and gait measures. The training took place at the University of Ottawa in an exercise room. Participants in the BMT and BMT+C groups trained one-on-one with a trainer for 1 hour, 3 times per week for 12 weeks. The warm-up consisted of walking at a self-selected pace on a treadmill for 5 minutes, followed by 8 flights of stairs. Participants then completed approximately 50 minutes of static and dynamic exercises on a variety of unstable objects on the balance obstacle course (Table 3; Appendix 1). For example, center of mass (COM) and base of support (BOS) perturbations on the both sides up (BOSU) ball, walking in tandem along half foam rollers, weaving around foam rollers when walking across balance pods, balancing on a

Table 2. Numbers counted during the TUGcog (Mean \pm SD) and the number of participants who spilled water during the TUGman

Group	Baseline		Post-training		12-week follow-up		Numbers Counted	Spills	Numbers Counted	Spills
	Numbers Counted	Spills	Numbers Counted	Spills	Numbers Counted	Spills				
BMT	4.22 \pm 1.52	7/15	3.91 \pm 1.26	7/15	4.16 \pm 1.35	6/15	-	-	-	-
BMT+C	4.13 \pm 0.98	5/14	3.91 \pm 1.20	5/14	4.17 \pm 1.17	3/14	-	-	-	-
Control	4.05 \pm 1.11	3/12	4.41 \pm 0.88	5/12	4.37 \pm 1.03	2/12	-	-	-	-
Preliminary Study	Session 1		Session 2		Session 3		Session 4		Session 5	
	Numbers Counted	Spills	Numbers Counted	Spills	Numbers Counted	Spills	Numbers Counted	Spills	Numbers Counted	Spills
	4.97 \pm 1.36	2/10	4.83 \pm 1.01	3/10	5.75 \pm 1.34	4/10	5.60 \pm 1.09	3/10	5.60 \pm 1.18	2/10

Table 3. Description of movements and activities of balance obstacle course of level 1

Obstacle Course Exercises
Step over a skip rope in the medial-lateral direction
Reach laterally high and low on foam surface with feet together
Stand on two balance disks with feet apart
Step and turn 360° on the BOSU
Stand on a firm surface with feet together while pulling elastic bands
Walk in tandem along a taped path
Stand on foam with feet apart
Stand with one foot on the square wobble board oriented in the medial-lateral direction and the other foot on the balance disk
Rotate around the perimeter edges of the circular wobble board both directions
Step onto and off of the stepper in the anterior-posterior direction
Side step along half foam rollers
Walk across staggered balance pods
Seated in a chair, pick up a ball from the ground on one side and move it to the ground on the other side with feet lifted

square or circular wobble board arranged in the medial-lateral (ML), anterior-posterior, or diagonal direction, trunk stability exercises on a chair or stability ball, and random changes in walking direction. While participants were negotiating the obstacle course, they also completed a second task, such as: holding a bin, moving a medicine ball up and down, moving a ball around the body, bouncing a ball, and catching and throwing a bean bag (Appendix 2). The training program was progressive such that as participants improved, the physical exercises as well as the second tasks became more difficult. For instance, the level of difficulty of the exercises on the obstacle course was altered by manipulating BOS, perturbing the COM and/or BOS, changing the direction of tilt of the wobble board, etc. The difficulty of the second task was altered by adding weight to an object, completing the task faster, changing a clear object to an opaque object to partially occlude vision, etc. In order for the trainer to increase the fixed level of difficulty in the next session, the participant must have successfully completed the exercise without losing their balance (e.g., stepping out of tandem, or using the wall or the trainer as a support). The training programs were individualized because each participant progressed at their own pace. Finally, participants stretched all major muscle groups while balancing for 2 minutes.

In addition to the physical and second task exercises, the BMT+C group also completed a wide variety of cognitive tasks that challenged different areas of cognition while on the obstacle course such as: categorization of words, spelling words forwards or backwards, telling a random story, and counting the occurrence of letters or numbers in an auditory sequence (Appendix 3). None of the cognitive tasks required gaze fixation or manual manipulation. The cognitive tasks were also fixed, individualized, and progressive.

Following the 12-week training, participants in the BMT and BMT+C groups were encouraged to stay physically active. They were informed of a free, city-funded exercise

program, and if this did not suit their interests, they were encouraged to find some form of physical activity to engage in. Participants in the control group were asked to keep their lifestyle the same throughout the study, but were encouraged to be physically active at the 12-week follow-up session.

The control group was asked not to alter their daily routine during the experiment. Blinding of investigators was not possible because the investigators supervised and conducted the training sessions.

Adherence

Adherence was examined by assessing the mean number of sessions attended out of a total of 36 one-hour sessions. Participants were required to attend at least 29 out of 36 sessions (i.e., 80% adherence rate) otherwise they would be excluded from the analysis. Participants received free parking during the experiment as recompense.

Preliminary study

Ten healthy older adults completed the aforementioned experimental protocol once per week for 5 weeks in order to determine the stability of the TUG, TUGcog, and TUGman over time. Because this is part of a larger experiment, it should be noted that on each testing day, participants got through three testing protocols. The dual-task postural testing protocol (i.e., Experiment 4) was performed first, followed by the functional mobility testing protocol (i.e., Experiment 3), followed by the dual-task obstacle clearance testing protocol (i.e., Experiment 5). Participant characteristics are reported in Table 1.

Statistical analyses

For the intervention, separate three-way repeated measures analyses of variance (ANOVAs) were performed on Session (baseline, post-training, 12-week follow-up) x Condition

(TUG, TUGcog, TUGman) x Group (BMT group, BMT+C group, control group) in order to determine whether functional mobility improved after balance training. For the preliminary study, separate two-way repeated measures ANOVAs were performed on Session (1-5) x Condition (TUG, TUGcog, TUGman) in order to determine if there was a repeated exposure effect. Separate independent samples t-tests were conducted on the TUG, TUGcog, and TUGman between the pooled 5 sessions of the preliminary study and the baseline data from the intervention in order to determine if the groups were comparable. Fisher's Least Significant Difference post-hoc comparisons were performed to determine location of significance. Statistical significance was set at $p < 0.05$.

RESULTS

Effects of balance training

First, there was no differences on the TUG, TUGcog, or TUGman between groups at baseline ($p > 0.05$). A significant Session by Condition by Group interaction was exposed for the time to completion of the TUG, TUGcog, and TUGman ($F_{(2, 39)} = 2.15, p < 0.05, \eta^2 = 0.19$). Post hoc analyses revealed that both the BMT ($F_{(1, 14)} = 44.43, p < 0.05, \eta^2 = 0.76$) and BMT+C ($F_{(1, 13)} = 48.75, p < 0.05, \eta^2 = 0.78$) groups walked significantly faster on the TUG ($p < 0.05$), TUGcog ($p < 0.05$), and TUGman ($p < 0.05$) between the baseline and post-training sessions, and the BMT ($F_{(1, 26)} = 12.37, p < 0.05, \eta^2 = 0.31$) and BMT+C ($F_{(1, 25)} = 14.54, p < 0.05, \eta^2 = 0.35$) walked significantly faster on the TUG ($p < 0.05$), TUGcog ($p < 0.05$), and TUGman ($p < 0.05$) at the post-training session compared to the control group (Table 4). No significant changes emerged for the control group.

Effect of BMT+C on the TUGcog

There was no significant difference on the TUGcog between the BMT and BMT+C groups ($p>0.05$).

TUG measures at the 12-week follow-up

Follow-up analyses of the Session by Condition by Group interaction revealed that the BMT ($F_{(1, 14)}=41.73, p<0.05, \eta^2=0.75$) and BMT+C ($F_{(1, 13)}=50.00, p<0.05, \eta^2=0.79$) groups walked significantly faster on the TUG ($p<0.05$), TUGcog ($p<0.05$), and TUGman ($p<0.05$) between the baseline and the follow-up sessions, and the BMT ($F_{(1, 26)}=9.66, p<0.05, \eta^2=0.28$) and BMT+C ($F_{(1, 25)}=16.50, p<0.05, \eta^2=0.41$) walked significantly faster on the TUG ($p<0.05$), TUGcog ($p<0.05$) and TUGman ($p<0.05$) at the 12-week follow-up compared to the control group (Table 4). No significant changes emerged for the control group.

Adherence, attrition and impact of the training programs

The training groups showed high adherence rates, with the BMT group adhering to $91.5\pm 7.2\%$ and the BMT+C group adhering to $95.9\pm 6.4\%$ of the program. The total attrition rate from the baseline test to the follow-up was 11.8% (2/17) for the BMT group, 17.6% for the BMT+C group (3/17), and 13.3% for the control group (2/15).

Preliminary study

The stability of the TUG, TUGcog, and TUGman over 5 testing sessions was shown by a lack of a main effect of Session ($F_{(1,9)}=1.82, p>0.05$) (Table 5). No significant differences in the TUG ($t(50)=0.61, p>0.05$), TUGcog ($t(50)=1.10, p>0.05$), and TUGman ($t(50)=0.79, p>0.05$) were shown of the pooled data across 5 sessions of the preliminary study and the baseline data of the BMT, BMT+C and control groups (Table 6).

Table 4. Average (± 1 SD) of the timed-up-and-go (TUG), TUG cognitive (TUGcog), and TUG manual (TUGman) in seconds for the balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and control groups

Group	Baseline			Post-training			12-week follow-up		
	TUG	TUGcog	TUGman	TUG	TUGcog	TUGman	TUG	TUGcog	TUGman
BMT	6.50 \pm 0.78	7.68 \pm 0.97	8.45 \pm 1.05	5.66 \pm 0.60 \dagger *	6.35 \pm 0.92 \dagger *	7.43 \pm 0.72 \dagger *	5.73 \pm 0.72 \dagger *	6.61 \pm 0.99 \dagger *	7.70 \pm 1.14 \dagger *
BMT+C	6.82 \pm 0.90	7.24 \pm 1.20	8.32 \pm 1.07	5.71 \pm 0.74 \dagger *	6.08 \pm 0.87 \dagger *	7.32 \pm 1.13 \dagger *	5.92 \pm 0.82 \dagger *	6.34 \pm 0.85 \dagger *	7.46 \pm 0.91 \dagger *
Control	7.04 \pm 0.72	7.76 \pm 1.06	8.62 \pm 1.22	6.93 \pm 0.84	7.35 \pm 0.89	8.73 \pm 1.48	6.72 \pm 0.55	7.40 \pm 0.79	9.09 \pm 1.00

\dagger Indicates significant differences compared to baseline ($p < 0.05$)

* Indicates significant differences compared to the control group ($p < 0.05$)

Table 5. Preliminary study on repeated testing (n=10) (Mean \pm SD)

Test	Session 1	Session 2	Session 3	Session 4	Session 5
TUG (s)	6.8 \pm 0.9	6.5 \pm 1.0	6.7 \pm 1.1	6.6 \pm 1.2	6.6 \pm 1.0
TUGcog (s)	7.4 \pm 1.6	7.0 \pm 1.6	7.1 \pm 1.5	7.1 \pm 1.4	6.9 \pm 1.2
TUGman (s)	8.5 \pm 1.4	8.2 \pm 1.3	8.1 \pm 1.7	8.3 \pm 1.3	8.0 \pm 1.2

Table 6. Comparison of results between the preliminary study and baseline of the intervention (Mean \pm SD)

Test	Mean of 5 repeated sessions (n=10)	Baseline of intervention (n=41)
TUG (s)	6.6 \pm 1.0	6.8 \pm 0.8
TUGcog (s)	7.1 \pm 1.4	7.6 \pm 1.1
TUGman (s)	8.2 \pm 1.3	8.5 \pm 1.1

DISCUSSION

This exploratory experiment showed three main findings. First, the BMT group and the BMT+C group improved functional mobility compared to the control group. Second, the BMT+C did not show further improvements across these tests following the intervention compared to the BMT group. Third, both the BMT and the BMT+C groups maintained their improvements in the TUG, TUGcog, and TUGman after the 12-week follow-up.

Effect of balance training

Improvements in functional mobility as evidenced by the TUG have been delineated in previous balance training experiments [9, 13-18], which corroborates our findings. Horak (2006) described the systems approach to understanding balance as an interaction of biomechanical constraints, movement strategies, sensory strategies, orientation in space, control of dynamics, and cognitive processing [27]. Both balance training programs in the present experiment were multifactorial as they were designed to train each of these systems. For example, sensory strategies were challenged when participants negotiated obstacles of varying textures and consistencies, orientation in space was challenged when participants were required to continuously align themselves on a wobble board, and cognitive processing was challenged by adding an additional task. The TUG is an assessment that includes several important functional mobility skills, such as turning, sit-to-stand transitions, as well as straight-ahead gait [28]. However, the TUG along with other functional clinical scales is limited since it is not possible to isolate which specific balance and gait subcomponents are affected when the score is below normal [29]. Our experiment suggests that the addition of cognitive training to a balance and mobility training program is not necessary to improve functional mobility, as there were no differences between groups on the TUG, TUGcog, or TUGman. It is unknown whether dual-

task balance training provides additional improvements in functional mobility, since this experiment did not include single-task balance training. However, our results demonstrate improved functional mobility, which was likely attributed to training numerous balance systems.

The current baseline TUG scores were within, but on the faster end of the norms for independently functioning older adults [5, 30, 31] thus supporting the characterization that the current sample of older adults was healthy and active. In fact, each participant was below the clinical cut-off point of 12 s, which is a recognized threshold for normal TUG performance in community-dwelling older adults [32]. A time to completion on the TUG of 6 s has been reported to be in the 90th percentile for healthy community-dwelling older adults [32]. Interestingly, both the BMT and the BMT+C groups improved their time to completion such that they obtained faster TUG scores that ranged not only outside of the population norms [6], but surpassing the 90th percentile [32] suggesting that both training groups reached a superior level of functional mobility. An average decrease in TUG time of -0.8 ± 0.5 s [9] has been reported to be clinically significant. When comparing post training to baseline, the BMT group showed a -0.9 ± 0.6 s in the TUG, -1.5 ± 0.9 s in the TUGcog, and -1.1 ± 0.9 s in the TUGman. In comparison, the BMT+C group displayed a -1.1 ± 0.6 s in the TUG, -1.2 ± 0.9 s in the TUGcog and -1.0 ± 0.7 s in the TUGman. This suggests that clinically significant improvements were exhibited in functional mobility following the BMT and BMT+C 12-week training.

We are confident that this improvement in functional mobility was not a function of repeated exposure as the TUG, TUGcog, and TUGman proved to be stable over 5 testing sessions. This emphasizes that the repeated administration of the TUG, TUGcog, and TUGman once per week for 5 weeks (preliminary study), or 3 times over the course of 6 months (in the control group, for example) does not result in improved performance. Conversely, previous work

that has examined the reliability of the TUG, TUGcog, and TUGman after the repeated administration on 5 consecutive days found excellent test-retest reliability with ICC values ranging from 0.851-0.960 [21]. In the present pilot study, improvements in the TUG following 12 weeks of balance training can likely be attributed to the training since most balance training interventions were longer than one week [9, 13-16, 18].

Effect of BMT+C on the TUGcog

The hypothesis that the BMT+C group would display further improvements in functional mobility compared to the BMT group was incorrect. It was particularly surprising that there were no improvements in the TUGcog as the BMT+C group specifically trained the ability to count backwards while performing balance and mobility exercises. Previous research has shown that simply performing computerized cognitive tasks without physical exercises improves standing on one leg, dynamic posturography as measured by the sensory organization test, the 40 foot walk test, and the time to completion of 5 sit-to-stands [17]. Similarly, other work has shown further improvements in gait velocity and single support time when walking while counting backwards as a result of strength and balance exercises with the addition of a cognitive-motor dance game compared to only the strength and balance exercises [20]. However, most of the outcome measures were not significantly different between groups [20], which may suggest that the added cognitive training to a balance intervention may only contribute to small additional improvements compared to the balance exercises themselves. Perhaps differences between training groups were not revealed due to a lack in sensitivity of the TUGcog measure, or the small sample size. Alternatively, it is possible that this experiment did not show added improvements in functional mobility in the BMT+C group as both training programs were consistently challenging and were of moderate to high intensity, which has been evidenced to

evoke large improvements [33]. More likely, we believe that because the attentional demand was high in both training programs due to the simultaneous performance of multiple tasks, functional mobility also improved to the same extent. Regardless of the nature of the tasks, simultaneously performing multiple tasks can be attention demanding. Therefore, we propose that consistently training balance and mobility at a high attention demand improves functional mobility in older adults.

TUG measures at the 12-week follow-up

As hypothesized, our findings confirm that both the BMT group and the BMT+C group not only improved functional mobility during training, but maintained their improved functional mobility after the 12-week follow-up period compared to the control group. Few experiments have examined the effects of declines in performance after a follow-up period. After exercise interventions in older adults, two experiments confirm that the TUG maintains improvements after a follow-up period [22, 23], one experiment showed that the TUG declined relative to post intervention but remains above baseline values [34], and another experiment revealed that the TUG returned to baseline values [35] but may have been as a result of a ceiling effect in performance as TUG values were faster than the norm. Other measures of physical fitness seem to exhibit greater declines in performance than functional mobility. For example, significant declines in strength [22, 33, 34], reactive balance [35], reaching [22], chair stand repetitions [22], chair rising time [36], 6-minute walk distance [36], and flexibility [36] have been observed. This literature suggests that these measures may present signs of deterioration before functional mobility perhaps because the TUG involves a number of balance systems. It is also possible that the older adults maintained a higher physical activity level upon the completion of the training programs which may have led to sustained improvements in functional mobility.

To reiterate, the improvements shown in the TUG, TUGcog, and TUGman after a 12-week follow-up are unlikely due to the repeated administration of these tests. Our results show that the baseline data of the BMT, BMT+C, and control groups were not different from results of the preliminary study (across 5 testing sessions). This lack of significant differences suggests that the maintenance in performance on the TUG, TUGcog, and TUGman for the BMT and BMT+C groups at the follow-up was in fact due to sustained functional mobility as opposed to a repeated exposure to these measures.

Adherence, attrition and impact of the training programs

Both training programs proved to be feasible, with the BMT group adhering to $91.5 \pm 7.2\%$ and the BMT+C group adhering to $95.9 \pm 6.4\%$ of the program, which is higher than the reported average of 89% for individualized training protocols [37]. The median attrition rate for interventions has been reported to be 16.2% [37] from baseline to the post-test, which is higher than both the BMT and BMT+C groups 11.8% (2/17 participants for both groups) and 0% for the control group (0/14). The total attrition rate from the baseline test to the follow-up was 11.8% (2/17) for the BMT group, 17.6% for the BMT+C group (3/17), and 14.3% for the control group (2/14). This exploratory experiment provided supervised and personalized balance training in healthy older adults, while in other experiments, this has been offered for at risk populations [e.g., 38] or unsupervised personalized home-based training programs in at-risk populations [e.g., 39]. Our pilot results indicate that personalized multifactorial balance training has functional mobility benefits in healthy older adults, and should be considered in the design of future intervention experiments.

Limitation

The main limitation of this exploratory experiment was that the assessor supervised and conducted the training sessions. Therefore, the assessor was not blinded to group allocation. In order to minimize this bias, the assessor followed a standardized testing protocol and provided the same instructions to each participant without giving any feedback on their TUG, TUGcog, or TUGman performance.

CONCLUSION

The two training programs (BMT and BMT+C) demonstrated improvements in functional mobility and sustained these improvements after a 12-week follow-up. The additional cognitive training that the BMT+C group received did not elicit any further benefits in functional mobility compared to the BMT group. According to the results of the preliminary study, the improvements in the TUG, TUGcog, and TUGman in the BMT and BMT+C groups can likely be attributed to the training rather than the repeated exposure to these tests. In sum, this exploratory experiment asserts that 12 weeks of individualized and progressive multi-task balance training is an effective method to improve functional mobility in healthy community-dwelling older adults. The results from this experiment will be helpful in designing a future single-blinded randomized controlled trial

COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of potential conflicts of interest

The authors declare that they have no conflict of interest.

Research involving human participants

All procedures performed in experiments involving human participants were in accordance with the University of Ottawa Research Ethics Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all participants included in this experiment.

ACKNOWLEDGEMENTS

A special thank you to Dominique Mercier and Eliane Dionne who aided with the one-on-one balance training. This project was financed by an internal grant from the University of Ottawa [grant number 119656].

REFERENCES

- [1] Tinetti ME, Speechley M, Ginter SF (1988) Risk factors for falls among elderly persons living in the community. *N Engl J Med* 319:1701–1707.
- [2] Lord SR, Ward JA, Williams P, Anstey KJ (1994) Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr Soc* 42:1110–1117.
- [3] Pijnappels M, Delbaere K, Sturnieks DL, Lord SR (2010) The association between choice stepping reaction time and falls in older adults—a path analysis model. *Age Ageing* 39:99-104.
- [4] Brown CJ, Friedkin RJ, Inouye SK (2004) Prevalence and outcomes of low mobility in hospitalized older patients. *J Am Geriatr Soc.* 52:1263-1270.
- [5] Podsiadlo D, Richardson S (1991) The timed "up & go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc* 39:142-148.
- [6] Steffen TM, Hacker TA, Mollinger L (2002) Age- and gender-related test performance in community-dwelling elderly people: six-minute walk test, berg balance scale, timed up & go test, and gait speeds. *Phys Ther* 82:128-137.
- [7] Hofheinz M, Schusterschitz C (2010) Dual task interference in estimating the risk of falls and measuring change: a comparative, psychometric study of four measurements. *Clin Rehabil* 24:831-842.
- [8] Shumway-Cook A, Brauer S, Woollacott M (2000) Predicting the probability for falls in community-dwelling older adults using the timed up & go test. *Phys Ther* 80:896-903.
- [9] Thiebaud RS, Funk MD, Abe T (2014) Home-based resistance training for older adults: a systematic review. *Geriatr Gerontol Int* 14:750-757.

- [10] Schoene D, Lord SR, Delbaere K, Severino C, Davies TA, Smith ST (2013) A randomized controlled pilot study of home-based step training in older people using videogame technology. *PLoS One* 8:e57734.
- [11] Bieryla KA (2015) Xbox Kinect training to improve clinical measures of balance in older adults: a pilot study. *Aging Clin Exp Res*. Sept 16. Epub ahead of print.
- [12] Bieryla KA, Dold NM (2013) Feasibility of Wii Fit training to improve clinical measures of balance in older adults. *Clin Interv Aging* 8:775-781.
- [13] Agmon M, Kelly VE, Logsdon RG, Nguyen H, Belza B (2015) The effects of EnhanceFitness (EF) training on dual-task walking in older adults. *J Appl Gerontol* 34:128-142.
- [14] Dias CP, Toscan R, de Camargo M, Pereira EP, Griebler N, Tiggemann CL (2015) Effects of eccentric-focused and conventional resistance training on strength and functional capacity of older adults. *Age Dordr* 37:99.
- [15] Haslinger W, Müller L, Sarabon N, Raschner C, Kern H, Löfler S (2015) A novel device to preserve physical activities of daily living in healthy older people. *J Aging Phys Act* 23:569-579.
- [16] Kitazawa K, Showa S, Hiraoka A, Fushiki Y, Sakauchi H, Mori M (2015) Effect of a dual-task net-step exercise on cognitive and gait function in older adults. *J Geriatr Phys Ther* 38:133-140.
- [17] Li KZ, Roudaia E, Lussier M, Bherer L, Leroux A, McKinley PA (2010) Benefits of cognitive dual-task training on balance performance in healthy older adults. *J Gerontol A Biol Sci Med Sci* 65:1344-1352.
- [18] Ory MG, Smith ML, Jiang L, Lee R, Chen S, Wilson AD, Stevens JA, Parker EM (2015) Fall prevention in community settings: results from implementing stepping on in three States. *Front Public Health* 27:232.

- [19] Tsuji T, Kitano N, Tsunoda K, Himori E, Okura T, Tanaka K (2014) Short-term effects of whole-body vibration on functional mobility and flexibility in healthy, older adults: a randomized crossover study. *J Geriatr Phys Ther* 37:58-64.
- [20] Pichierri G, Murer K, de Bruin ED (2012) A cognitive-motor intervention using a dance video game to enhance foot placement accuracy and gait under dual task conditions in older adults: a randomized controlled trial. *BMC Geriatr* 12:74.
- [21] Smith E, Walsh L, Doyle J, Greene B, Blake C (2016) The reliability of the quantitative timed up and go test (QTUG) measured over five consecutive days under single and dual-task conditions in community dwelling older adults. *Gait Posture* 43:239-244.
- [22] Carvalho MJ, Marques E, Mota J (2009) Training and detraining effects on functional fitness after a multicomponent training in older women. *Gerontology* 55:41-48.
- [23] Lacroix A, Kressig RW, Muehlbauer T, Gschwind YJ, Pfenninger B, Bruegger O, Granacher U (2015) Effects of a supervised versus an unsupervised combined balance and strength training program on balance and muscle power in healthy older adults: a randomized controlled trial. *Gerontology* Dec 9. Epub ahead of print.
- [24] Folstein M, Folstein SE, McHugh PR. (1975). Mini-mental state a practical method for grading the cognitive state of patients for the clinician. *J Psychiat Res* 12:189-198.
- [25] Powell LE Myers AM (1995) The activities-specific balance confidence (ABC) scale. *J Gerontol A Biol Sci Med Sci* 50:28-34.
- [26] Godin G, Shephard RJ (1985) A simple method to assess exercise behavior in the community. *Can J Appl Sport Sci* 10:141-146.
- [27] Horak FB (2006) Postural orientation and equilibrium: what we need to know about neural control of balance to prevent falls? *Age Ageing* 35:7-11.

- [28] Salarian A, Zampieri C, Horak FB, Carlson-Kuhta P, Nutt JG, Aminian K (2009) Analyzing 180 degrees turns using an inertial system reveals early signs of progression of parkinson's disease. *Conf Proc IEEE Eng Med Biol Soc* 1:224–227.
- [29] Zampieri C, Salarian A, Carlson-Kuhta P, Aminian K, Nutt JG, Horak FB (2010) An instrumented timed up and go test characterizes gait and postural transitions in untreated parkinson's disease. *J Neurol Neurosurg Psychiatry* 81:171–176.
- [30] Newton RA (1997) Balance screening of an inner city older adult population. *Arch Phys Med Rehabil* 78:587–591.
- [31] Mathias S, Nayak US, Isaacs B (1986) Balance in elderly patients: the “Get-Up and Go” Test. *Arch Phys Med Rehabil* 67:387–389.
- [32] Bischoff H, Stähelin H, Monsch A, Iversen MD, Weyh A, von Dechend M, Akos R, Conzelmann M, Dick W, Theiler R (2003) Identifying a cut-off point for normal mobility: a comparison of the timed ‘up and go’ test in community-dwelling and institutionalised elderly women. *Age Ageing* 32:315-320.
- [33] Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ (1990) High-intensity strength training in nonagenarians. Effects on skeletal muscle. *JAMA* 263:3029–3034.
- [34] Kalapotharakos VI, Diamantopoulos K, Tokmakidis SP (2010) Effects of resistance training and detraining on muscle strength and functional performance of older adults aged 80 to 88 years. *Aging Clin Exp Res* 22:134-140.
- [35] Coetsee C, Terblanche E (2015) The time course of changes induced by resistance training and detraining on muscular and physical function in older adults. *Eur Rev Aging Phys Act* 29;12:7.

- [36] Seco J, Abecia LC, Echevarría E, Barbero I, Torres-Unda J, Rodriguez V, Calvo JI (2013) A long-term physical activity training program increases strength and flexibility, and improves balance in older adults. *Rehabil Nurs* 38:37-47.
- [37] Nyman SR, Victor CR (2011) Older people's recruitment, sustained participation, and adherence to falls prevention interventions in institutional settings: a supplement to the Cochrane systematic review. *Age Ageing* 40:430-436.
- [38] Subramaniam S, Wan-Ying Hui-Chan C, Bhatt T (2014) A cognitive-balance control training paradigm using wii fit to reduce fall risk in chronic stroke survivors. *J Neurol Phys Ther*. 38:216-225.
- [39] Bamgbade S, Dearmon V (2016) Fall prevention for older adults receiving home healthcare. *Home Health Now* 34:68-75.

CHAPTER 6: EXPERIMENT 4**Balance and mobility training with or without concurrent cognitive training does not improve posture, but improves reaction time in healthy older adults**

A version of this article has been published in Gait and Posture, and has been formatted accordingly. Both Drs. Yves Lajoie and Nicole Paquet give their consent to the inclusion of this manuscript in the current dissertation.

Jehu, D.A., Paquet, N., Lajoie, Y.

Corresponding author

Yves Lajoie, PhD.
University of Ottawa, Health Sciences, School of Human Kinetics
125 University St, Ottawa, Ont., Canada, K1N6N5
Phone: +1-613-562-5800 ext. 4273
Fax: (613) 562-5497
Email: ylajoie@uottawa.ca

ABSTRACT

Background and aims: The purpose was to determine whether balance and mobility training (BMT) or balance and mobility plus cognitive training (BMT+C) would reduce postural sway and reaction time (RT) and maintain these improvements after a 12-week follow-up in healthy older adults. *Methods:* Participants were allocated to the BMT (n=15; age: 70.2±3.2), BMT+C (n=14; age:68.7±5.5), or control group (n=13; age: 66.7±4.2). The BMT group trained one-on-one, 3x/wk for 12 weeks on a balance obstacle course. The BMT+C group trained one-on-one, 3x/week for 12 weeks on a balance obstacle course while completing cognitive tasks.

Participants stood on a force plate for 30 s in feet-apart (FA) and semi-tandem (ST) positions while completing simple RT and choice RT tasks at baseline, at the 12-week post-training, and at the 12-week follow-up. Participants were instructed to stand as still as possible while verbally responding as fast as possible to the auditory cues. *Results:* No group differences in center of pressure (COP) Area, COP Velocity, or Sample Entropy of the COP displacement were shown after the training or 12-week follow-up, but the BMT and BMT+C showed faster RT after training and maintained these improvements at the 12-week follow-up compared to the control group. No differences in postural sway or RT emerged between the BMT and BMT+C groups.

Conclusion: Both training groups improved RT after the interventions and sustained these improvements over 12 weeks, but showed no reductions in postural sway. Multi-task balance training likely results in reduced attention demand.

Key words: postural control; reaction time; balance training; divided attention; older adults

1. Introduction

Falls are a major issue for older adults as one third fall each year [1]. Declines in physical and cognitive functioning have been identified as intrinsic fall risk factors [2]. Indeed, postural control and attention demand deteriorate in older compared to young adults [3]. This emphasizes the importance of research dedicated to improving balance and divided attention in older adults.

Numerous experiments have focused on improving balance and gait as well as preventing falls through a variety of exercise programs for older adults. A portion of these efforts have been devoted to examining whether postural control improves following training. However, there have been inconsistencies as to whether training programs yield decreased [4,5], no change [4,6,7,8], or increased postural sway in older adults [5,9]. In fact, a systematic review delineated that only 19% of balance outcome measures are reported to be significant following progressive resistance training in healthy community-dwelling older adults [10]. It is unclear why certain experiments have shown improvements while others have not; however some literature proposes that dual-task training is necessary to improve divided attention [11,12]. Other experiments have suggested that multifactorial exercise [13] as well as exercises targeting sensory systems [14] should be incorporated in order to elicit benefits to postural control.

Dual-task paradigms have been employed to evaluate the role of attention demand on motor control [15]. Postural control has been shown to be responsive to cognitive manipulations [16]. In fact, divided attention tasks have presented improved stability by shifting attention away from postural control [3]. In light of these findings, and that aging has been associated with declines in cognitive functioning [17] and reaction time (RT) [3], few preliminary experiments have combined divided attention training with balance training. Promising evidence suggests that the addition of visual and auditory discrimination training as well as visual-spatial RT training to

balance interventions may induce further improvements in posture, RT, and working memory [7,18].

The overarching purpose of this experiment was to determine whether 12 weeks of balance and mobility training (BMT) or 12 weeks of balance and mobility plus cognitive training (BMT+C) would improve center of pressure (COP) Area, COP Velocity, Sample Entropy of COP displacement in the medial-lateral and anterior-posterior directions, as well as audio-verbal RT compared to the control group. A second aim was to determine whether further improvements in posture and RT would be exposed in the BMT+C group compared to the BMT group. A third aim was to determine whether possible improvements in posture and RT after BMT and BMT+C would be maintained after the 12-week follow-up. We hypothesized that: 1) posture and RT would improve after training, as both programs involved multi-tasking, 2) BMT+C would elicit further improvements in posture and RT compared to BMT, as the addition of divided attention training to balance training has shown improvements in gross motor skills as well as divided attention [18], and 3) possible improvements in posture and RT would be sustained at the 12-week follow-up in both training groups.

2. Methods

2.1. Participants

Inclusion criteria consisted of being 60 years of age and older, having no self-reported musculoskeletal, neurological or sensory deficits that may affect balance, having normal or corrected to normal vision, living independently in the community, walking without an assistive device, obtaining 24 or greater on the Mini-Mental State Examination (MMSE), and being able to discriminate between high and low pitched auditory beeps. Participants in the BMT and

BMT+C groups must have attended 29/36 sessions (i.e., 80% adherence rate), otherwise they would have been excluded from the analysis.

Seventy-six community-dwelling older adults were assessed for eligibility. Twenty declined to participate, and 7 did not meet the age criteria and/or walked with an assistive device. Accounting for the 7 dropouts, 42 participants were block-randomized by age into the BMT group (n=15; age range: 65-76 years), the BMT+C group (n=14; age range: 60-77 years) and the control group (n=13; age range: 62-77 years). Participant characteristics are reported in Table 1.

2.2. Procedure

Participants began the testing session by reading and signing the informed consent form approved by the University of Ottawa Research Ethics Board. Participants then completed the Godin leisure-time physical activity questionnaire, which assesses weekly frequencies of mild, moderate, and vigorous physical activities performed for at least 15 minutes with the total weighted score calculated in the metabolic equivalent of the task (MET) [19] (Table 1). The similar baseline Godin scores across groups are indicative of a healthy and active sample. Next, participants stood on a force platform in a quiet laboratory with their feet-apart (FA) and feet in semi-tandem (ST) with arms at their sides while directing their gaze at an eye-level target 3 m in front of them. ST consisted of feet together with one foot placed adjacent to the arch of the forward foot. Participants' feet position was marked on the force platform at baseline to ensure consistent foot placement across trials and sessions. In conjunction with the 30 s postural task, participants were asked to perform two RT tasks: simple reaction time (SRT) and choice reaction time (CRT). During the SRT trials, participants were asked to verbally respond "tie" to random high pitched auditory cues. Between 5 and 7 stimuli were presented per trial and ranged from 3 to 7 seconds apart. During the CRT trials, participants were presented with random high and low

Table 1Participant characteristics (Mean \pm SD).

Group	Age (years)	Sex (m/f)	Height (cm)	Weight (kg)	BMI	Education (years)	MMSE (units)	Godin (MET)	# of Training Sessions Completed	Balance Training Level of Difficulty Attained	Cognitive Training Level of Difficulty Attained
BMT (n=15)	70.2 \pm 3.2	3/12	162.6 \pm 8.9	79.0 \pm 17.9	29.7 \pm 5.8	17.4 \pm 2.8	29.3 \pm 0.8	34.1 \pm 18.0	32.9 \pm 2.6	7.9 \pm 1.8	NA
BMT+C (n=14)	68.7 \pm 5.5	6/9	165.5 \pm 10.7	72.7 \pm 16.4	26.4 \pm 4.5	18.0 \pm 2.4	29.7 \pm 0.5	34.3 \pm 24.0	34.5 \pm 2.3	6.3 \pm 1.3	4.9 \pm 2.1
Control (n=13)	66.3 \pm 4.4	3/9	166.3 \pm 9.1	72.5 \pm 13.8	26.1 \pm 4.1	18.5 \pm 2.6	29.1 \pm 1.5	34.5 \pm 15.8	NA	NA	NA

auditory stimuli and were asked to respond “tie” and “tow”, respectively. These words were chosen as they begin with a hard consonant and they also resemble the words “high” and “low”, which were the two different pitches used. Between 5 and 7 stimuli were administered per trial and ranged from 3 to 8 seconds apart, of which 2 to 4 were low pitched. Trials were repeated if participants incurred two or more errors. Three 30 s trials were performed for each of the conditions (i.e., FA, FASRT, FACRT, ST, STSRT, and STCRT). Prior to the experimental conditions, a familiarization period was performed, including FA, FASRT, and FACRT for 30 s, at the beginning of each testing session. The instructions were to stand as still as possible while verbally responding as fast as possible, when applicable.

2.3. Data analysis

An mp3 recorder was attached to the participants’ arm and used to capture high and low auditory stimuli emitted by a piezoelectric speaker and the verbal responses in order to determine RT. The high-pitched signal was administered at a fixed frequency of 2850 Hz at 99 dB whereas the low-pitched signal was administered at a fixed frequency of 970 Hz at 95 dB for approximately 100 ms. The Audacity software was used to process RT, which was computed manually using vertical cursors from the beginning of the verbal response minus the onset of the auditory cue in ms.

An AMTI force plate (ORG-6-1000, Don Mills, ON, Canada) was used as a proxy to measure COP at a sampling frequency of 500 Hz. MatLab software (MathWorks Inc., MA, USA) was used to attain the COP 95% Area Ellipse, COP Velocity, and Sample Entropy of COP displacement in the medial-lateral and anterior-posterior directions. Sample entropy data were converted from cm to mm and desampled from a rate of 500 Hz to 100 Hz, in order to compare

the current study to previous work using sample entropy [16]. Trials were averaged for each experimental condition and these averages were used for analysis.

2.4. Intervention

Participants in the BMT and BMT+C groups trained one-on-one with a trainer for 1 hour, 3 times per week for 12 weeks. The warm-up consisted of walking at a self-selected pace on a treadmill for 5 minutes, followed by 8 flights of stairs. Participants then completed 13 static and dynamic exercises on a variety of unstable objects on the balance obstacle course for 50 minutes (Table 2; Appendix 1). If participants completed all of these exercises before the 50 minutes were finished, some exercises were randomly repeated in order to ensure that each participant received the same amount of balance training. While participants were negotiating the obstacle course, they also completed a second task, such as: holding a bin, moving a medicine ball up and down, and catching and throwing a bean bag (Appendix 2). The training program was progressive such that as participants improved, the physical exercises and second tasks became more difficult. For example, the level of difficulty of the exercises on the obstacle course was altered by manipulating the base of support, perturbing the center of mass and/or base of support, and changing the direction of tilt of the wobble board. The difficulty of the second task was altered by adding weight to an object, completing the task faster, changing a clear object to an opaque object to partially occlude vision, etc. In order for the trainer to increase the fixed level of difficulty in the next session, the participant must have successfully completed the exercise without losing their balance (e.g., stepping out of tandem, or using the wall or the trainer as a support; Table 2). The training programs were individualized because each participant progressed at their own pace. Finally, participants stretched all major muscle groups in the upper

Table 2

Description of movements and activities of level 1 of the balance obstacle course and associated cognitive tasks.

Obstacle Course Exercises	Cognitive Task Exercises
Step over a skip rope in the medial-lateral direction	N-back numbers *#
Reach laterally high and low on a foam surface with feet together	Letter sequencing *#
Stand on two balance disks with feet apart	Number sequencing *#
Step and turn 360 ° on the BOSU	N-back words *#
Stand on a firm surface with feet together while pulling elastic bands	Counting backwards † Θ
Walk in tandem along a taped path	Conversation and description on request †+
Stand on foam with feet apart	Arithmetic operations * •
Stand with one foot on the square wobble board oriented in the medial-lateral direction and one foot on the balance disk	Spelling to dictation *°
Rotate around the perimeter edges of the circular wobble board in both directions	Oral spelling †°
Step onto and off of the stepper in the anterior-posterior direction	Counting forwards † Θ
Side step along half foam rollers	Number lists *§
Walk across staggered balance pods	Naming †+
Seated in a chair, pick up a ball from the ground on one side and move it to the ground on the other side with feet lifted	Math fluency † •

* Represents tasks performed with auditory recording; † represents tasks performed without auditory recording; The following neuropsychological categories and subcategories were trained # Orientation and Attention: Working Memory/Mental Tracking; Θ Verbal Memory: Verbal Automatism; + Verbal Function and Language Skills: Discourse; • Concept Formation and Reasoning: Mathematical Procedures; ° Verbal Functions and Language Skills: Verbal Academic Skills; § Memory: Verbal Memory [21].

and lower legs and arms as well as chest and back while balancing for 2 minutes. Participants took breaks when necessary.

The BMT+C group also performed 13 different cognitive tasks that were associated with the respective balance task on the obstacle course that challenged the phonological loop and central executive components of the working memory model proposed by Baddeley and Hitch (1974) [20]. These cognitive tasks were chosen as they did not include a visual component since vision was required during the balance and manual task training. They were also chosen as they were all continuous cognitive tasks that constantly demanded attention. The majority of the cognitive tasks were made incrementally more difficult by completing the task faster, adding memorization, reciting a list in alphabetical order forwards (i.e., starting with words that begin with “a”) or backwards (i.e., starting with words that begin with “z”). The “conversation and description on request” cognitive task was made more difficult by, for example, involving memory, providing a random topic, and adding humor. Participants advanced on the fixed levels when there were no mistakes or breaks in speech (i.e., <3-5 s; Appendix 3). Table 2 highlights the specific neuropsychological processes that were trained for each cognitive task [21].

Following the 12-week training, participants in the BMT and BMT+C groups were encouraged to stay physically active. They were informed of a free, city-funded exercise program, and if this did not suit their interests, they were encouraged to find some form of physical activity to engage in. Participants in the control group were asked to keep their lifestyle the same throughout the study, but were encouraged to be physically active at the 12-week follow-up session.

The control group was not enrolled in any training program and was asked not to alter their daily activities during the experiment.

2.5. Statistical analyses

A mixed-design repeated measures analysis of variance (ANOVA) was performed to examine the Group (BMT group, BMT+C group, control group) by Session (baseline, post-training, 12-week follow-up) interaction effects for Area, Velocity, and Sample Entropy of COP displacement in the medial-lateral and anterior-posterior directions, and RT according to Stance difficulty and RT difficulty in order to determine whether posture and RT improved after balance training and sustained these improvements at the follow-up. When applicable, post-hoc least significant difference comparisons were performed. If Mauchly's test of Sphericity was violated, the Greenhouse-Geisser correction was performed. Statistical significance was set to $p < 0.05$.

3. Results

3.1. Baseline postural and RT characteristics between groups

No Group differences in Area ($F_{(2, 41)}=3.81, p > 0.05$), Velocity ($F_{(2, 41)}=0.48, p > 0.05$), Sample Entropy of the COP displacement in the medial-lateral ($F_{(2, 41)}=0.58, p > 0.05$) or anterior-posterior ($F_{(2, 41)}=0.63, p > 0.05$) directions, or RT ($F_{(2, 41)}=2.55, p > 0.05$) occurred at baseline.

3.2. Effect of Group, Session, and Group \times Session interactions on postural measures

There were no Group differences in Area ($F_{(2, 41)}=2.82, p > 0.05$), Velocity ($F_{(2, 41)}=0.16, p > 0.05$), or Sample Entropy of COP displacement in the medial-lateral ($F_{(2, 41)}=0.55, p > 0.05$) or in the anterior-posterior direction ($F_{(2, 41)}=0.80, p > 0.05$).

No differences in Session for Area ($F_{(2, 41)}=2.23, p > 0.05$), Velocity ($F_{(2, 41)}=1.03, p > 0.05$), or Sample Entropy of COP displacement in the anterior-posterior direction ($F_{(2, 41)}=2.30, p > 0.05$) emerged. The significant main effect of Session for Sample Entropy of COP displacement in the medial-lateral direction ($F_{(2, 41)}=3.72, p < 0.05, \eta^2=0.25$) revealed greater Sample Entropy during

the post-training and follow-up sessions compared to baseline ($p<0.05$), however no effect of Stance or RT was shown (Table 3).

No Group x Session interaction effects were observed for Area ($F_{(2, 41)}=1.89, p>0.05$), Velocity ($F_{(2, 41)}=1.47, p>0.05$), or Sample Entropy of COP displacement in the medial-lateral ($F_{(2, 41)}=1.38, p>0.05$) or in the anterior-posterior direction ($F_{(2, 41)}=0.95, p>0.05$).

3.3. Effect of Group, Session, and Group x Session interaction on RT

No Group differences in RT emerged ($F_{(2, 41)}=0.85, p>0.05$).

There was a significant main effect of Session ($F_{(2, 41)}=8.24, p<0.05, \eta^2=0.41$). The BMT group exhibited significantly faster RT during FASRT, FACRT, STSRT, STCRT at the post training compared to the baseline session, and significantly faster FACRT, STSRT, STCRT, at the follow-up compared to baseline ($p<0.05$). No significant differences in FASRT, FACRT, STSRT, STCRT were shown between the post training and follow-up sessions ($p>0.05$) (Figure 1).

In addition, post hoc analyses revealed that the BMT+C group presented significantly faster FASRT, STSRT ($p<0.05$) and a trend for faster FACRT ($p=0.056$) post training compared to baseline, and significantly faster FASRT and FACRT at the follow-up compared to baseline ($p<0.05$). No differences in FASRT, FACRT, STSRT, STCRT were shown between the post training and follow-up sessions ($p>0.05$) (Figure 1).

No differences in the control group were displayed across sessions ($p>0.05$).

The significant Group x Session interaction ($F_{(2, 41)}=2.76, p<0.05, \eta^2=0.19$) can be observed in Figure 1.

Table 3Postural measures by group and session (Mean \pm SD).

	Baseline			Post-training			Follow-up		
	BMT	BMT+C	Control	BMT	BMT+C	Control	BMT	BMT+C	Control
Area (cm/s ²)	3.77 \pm 2.85	2.98 \pm 2.34	4.24 \pm 3.40	3.84 \pm 2.84	3.18 \pm 2.26	4.46 \pm 3.71	3.71 \pm 3.23	3.39 \pm 2.55	4.93 \pm 4.28
Velocity (cm/s)	4.56 \pm 1.09	4.75 \pm 0.86	4.81 \pm 1.07	4.65 \pm 1.23	4.78 \pm 0.86	4.82 \pm 1.10	4.55 \pm 1.16	4.65 \pm 0.82	4.87 \pm 1.28
Entropy ML	0.15 \pm 0.11*	0.14 \pm 0.10*	0.17 \pm 0.13*	0.16 \pm 0.13	0.14 \pm 0.09	0.17 \pm 0.14	0.16 \pm 0.12	0.14 \pm 0.09	0.18 \pm 0.15
	†	†	†	*	*	*	†	†	†
Entropy AP	0.14 \pm 0.05	0.14 \pm 0.06	0.17 \pm 0.11	0.15 \pm 0.08	0.15 \pm 0.06	0.17 \pm 0.12	0.15 \pm 0.08	0.14 \pm 0.05	0.18 \pm 0.13

* Represents significant differences between baseline and post-training sessions; † represents significant differences between baseline and follow-up sessions ($p < 0.05$).

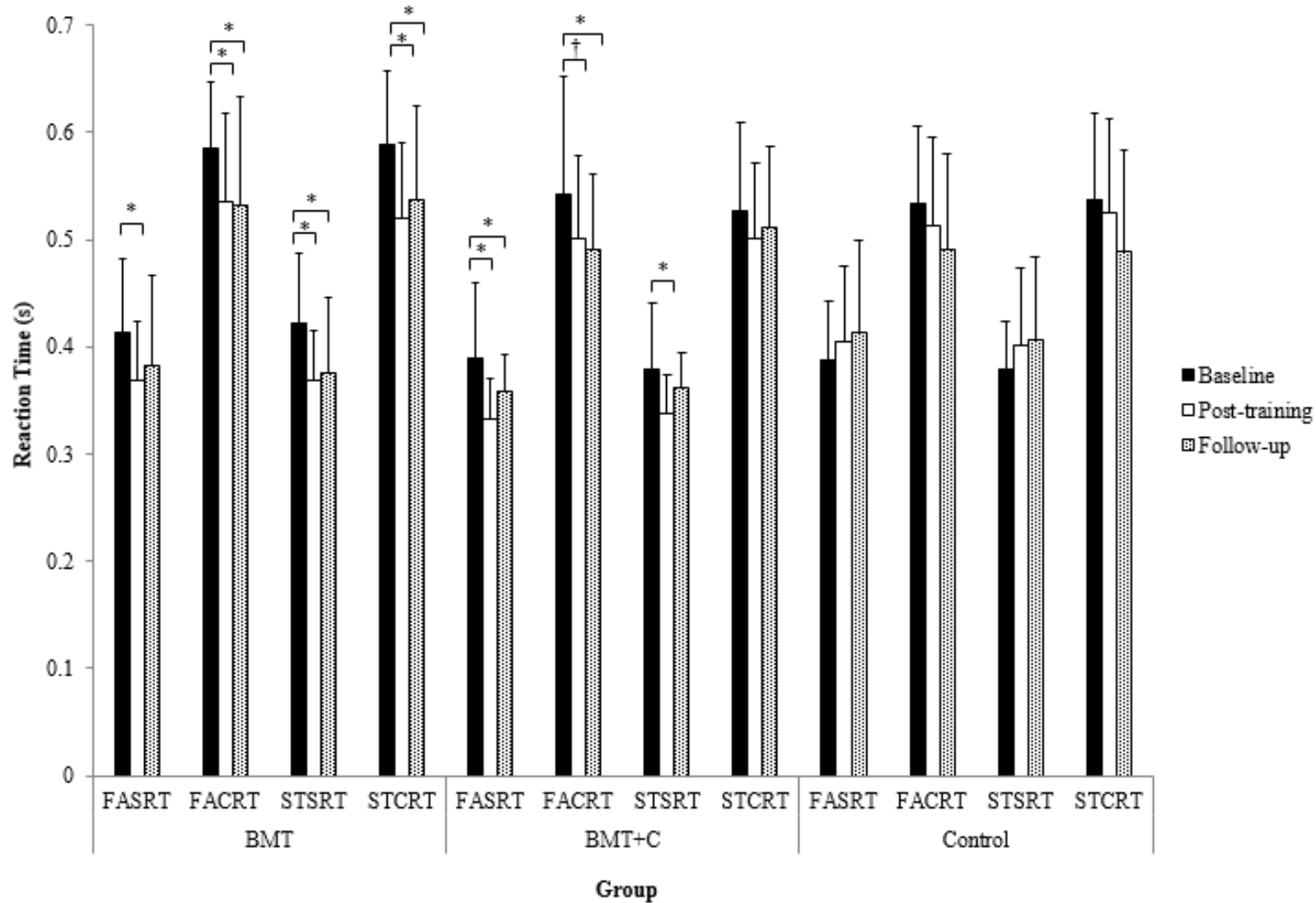


Fig. 1. Average (+ 1 SD) of simple reaction time (SRT) and choice reaction time (CRT) across feet apart (FA) and semi-tandem (ST) conditions for the balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and control groups at baseline, post-training, and 12-week follow-up. * $p < 0.05$; † $p = 0.056$.

4. Discussion

4.1. Main findings

The main findings of this experiment were: 1) postural sway did not decrease after either training program, but RT was faster for the BMT and BMT+C groups, 2) no differences in posture or RT were shown between the BMT+C and the BMT group, 3) RT sustained improvements at the follow-up in the BMT and BMT+C groups, while no change was found in the control group.

4.2. Effect of balance training on posture

No differences in area, velocity, or sample entropy were observed after training. Since previous research has documented that area [16], velocity [22], and sample entropy [23] are differentially modulated by attention, and since the current experiment showed an improved attention demand as demonstrated by improved RT in the BMT and BMT+C groups, we were somewhat surprised that no differences in postural sway emerged after training. However, the postural strategy in the medial-lateral direction may have changed as sample entropy increased during the post-training and follow-up sessions, but these effects were marginal and did not reach statistical significance between groups. Regularity of sway is measured with sample entropy. Stins et al. (2011) report that sample entropy (i.e., irregularity of the center of pressure) is the negative natural logarithm of an estimate of the conditional probability that subseries (epochs) of length that match pointwise within a specific tolerance range also match at the next point. Sample entropy of detrended anterior-posterior (AP) COP is dimensionless, and is measured on a scale of 0-2, with higher values (i.e., more irregular) being considered as more efficient and therefore more automatic. Perhaps postural sway is not a sensitive enough measure to capture improvements following balance training interventions. Functional tests, such as the

timed-up-and-go, may be a better indicator of training-related improvement. Our recent work revealed that BMT and BMT+C significantly improved functional mobility after training and sustained improvements at the 12-week follow-up [24].

In line with the current experiment, a wealth of research has reported null findings with respect to balance training on postural sway [4-8,11]. The lack of significant improvements in postural sway may stem from a number of possibilities. Because the participants were healthy and active, they may not have benefited as much as those who are inactive or at-risk for falls. Alternatively, the postural tests may not have been specific enough to express changes in postural sway. Likewise, it could be argued that the training program did not specifically train the ability to stand as still as possible and therefore did not result in improved sway during testing. Some literature has posited that interventions targeting precise variables show significant improvements on these tasks [5], whereas general training shows no transfer effect [6]. Since older adults tend to show less skill transfer compared to younger counterparts [25], perhaps the BMT and BMT+C groups exhibited task-specific improvements during the training (Table 1), but did not transfer these improvements to the testing protocol due to age-related effects.

4.3. Effect of BMT+C on posture and RT

Training cognition has been shown to improve gross motor skills [18]; however, the present experiment revealed no differences in postural sway between training groups. According to Table 1, the BMT group achieved 1.6 levels greater than the BMT+C group on the balance exercises, possibly because triple-tasking (i.e., concurrently performing a balance, manual, and cognitive task) resulted in a trade-off. However, perhaps the additional divided attention training assumed by the BMT+C group resulted in advancements in multi-tasking, leading to similar improvements in RT compared to the BMT group. The attention capacity theory predicates that

attention is limited because the system can only cope with a certain amount of information at a time [26]. Moreover, the task prioritization model postulates that improvements could occur in either or both tasks [27], which may explain the improvements in RT but not postural sway.

Although both training groups improved RT relative to the control group, the BMT+C group did not elicit further benefits, despite previous work demonstrating that training cognition improves cognition [18,28]. However, the improvements exposed in RT may not have been a function of cognitive training, but of the increased attention demand of coordinating multiple tasks provoked in both training groups. Alternatively, perhaps the RT testing was not sensitive enough to detect changes between the two training programs.

The BMT and BMT+C groups exhibited significantly faster SRT and CRT, while no changes were observed in the control group. Appendix 4 compares the effects of repeated administration of RT during the standing protocol at baseline (BMT, BMT+C, Control, and Preliminary Study 1), and after 12-weeks (BMT, BMT+C, and Control) or after 5 repeated testing sessions (Study 1). According to Appendix 4, the repeated exposure to RT led to faster CRT during standing compared to the BMT, BMT+C and control groups. It is possible that improvements over time may have been a function of gaining additional exposure to the specific outcome measures included in the dual-task postural control, dual-task functional mobility, and dual-task obstacle clearance testing protocols, as they were all performed within the same session. Importantly, the control group exhibited no repeated testing effects on RT, likely because they were only tested 3 times in 6 months, while the preliminary study group was tested 5 times within 5 weeks. This indicates that attention demand may be sensitive to repeated administration effects when the testing sessions are close in proximity. Therefore, the

improvements in RT exposed in the BMT and BMT+C groups are likely a function of dual-task training, in a larger part, as opposed to repeated testing.

4.4. Limitations

The BMT and BMT+C were individualized programs, potentially promoting considerable between-subject variability as participants progressed both on the obstacle course and cognitive tasks at different rates. Additionally, participants may have had less opportunity to improve any given cognitive or balance function due to the implementation of a range of tasks.

5. Conclusion

In sum, the BMT and BMT+C groups significantly improved attention demand after training, and preserved these improvements at the 12-week follow-up. No significant differences in postural sway were observed between groups. These findings are important for clinicians and researchers as BMT and BMT+C equally contributed to improved attention demand and sustained improvement over time in healthy older adults.

Conflict of interest statement

The authors have no conflict of interest to declare.

Acknowledgements

This research was supported by an internal grant from the University of Ottawa (119656).

References

- [1] Gill T, Taylor AW, Pengelly A. A population-based survey of factors relating to the prevalence of falls in older people. *Gerontology* 2005;51:340e5.
- [2] Lord SR, Ward JA, Williams P, Anstey KJ. Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr Soc* 1994;42:1110–7.
- [3] Huxhold O, Li SC, Schmiedek F, Lindenberger U. Dual-tasking postural control: Aging and the effects of cognitive demand in conjunction with focus of attention. *Brain Res Bull* 2006;69:294-305.
- [4] Markovic G, Sarabon N, Greblo Z, Krizanic V. Effects of feedback-based balance and core resistance training vs. Pilates training on balance and muscle function in older women: a randomized-controlled trial. *Arch Gerontol Geriatr.* 2015;61(2):17-23.
- [5] Wolf SL, Barnhart HX, Ellison GL, Coogler CE. The effect of tai chi quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. Frailty and Injuries: Cooperative studies on intervention techniques. *Phys Ther* 1997;77(4):371-81.
- [6] Jehu D. The effects of a multifactorial exercise and balance training program on balance control in older adults. Brock University, St. Catharines, Ontario, Canada; 2012.
- [7] Paquette MR, Li Y, Hoekstra J, Bravo J. An 8-week reactive balance training program in older healthy adults: A preliminary investigation. *J Sport Health Sci* 2015;263e269
- [8] Weerdesteyn V, Rijken H, Geurts AC, Smits-Engelsman BC, Mulder T, et al. A five-week exercise program can reduce falls and improve obstacle avoidance in the elderly. *Gerontol* 2006;52:131-41.

- [9] Lord S, Ward J, Williams P, Strudwick M. The effect of a 12-month exercise trial on balance, strength, and falls in older women: A randomized controlled trial. *Am Geriatr Soc* 1995;43:1198-206.
- [10] Orr R, Raymond J, Fiatarone Singh M. Efficacy of progressive resistance training on balance performance in older adults: A systematic review of randomized controlled trials. *Sports Med* 2008;38(4):317-43.
- [11] Hall CD, Miszko T, Wolf SL. Effects of Tai Chi intervention on dual task ability in older adults: A pilot study. *Arch Phys Med Rehabil* 2009;90(3):525–529.
- [12] Melzer I, Marx R, Kurz I. Regular exercise in the elderly is effective to preserve the speed of voluntary stepping under single-task condition but not under dual-task condition. *Gerontol* 2009;55(1):49–57.
- [13] Shumway-Cook A, Gruber W, Baldwin M, Liao S. The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. *Phys Ther* 1997;77(1):46-57.
- [14] Alfieri FM, Riberto M, Gatz LS, Ribeiro C P, Lopes JA, Battistella LR. Comparison of multisensory and strength training for postural control in the elderly. *Clin Interv Aging* 2012;7:119–25.
- [15] Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: A review of an emerging area of research. *Gait Posture* 2002;16:1-14.
- [16] Polskaia N, Lajoie Y. Reducing postural sway by concurrently performing challenging cognitive tasks. *Hum Mov Sci* 2016;46:177-83.
- [17] Deary IJ, Corley J, Gow AJ, Harris SE, Houlihan LM, Marioni RE, et al. Age-associated cognitive decline. *Br Med Bull* 2009;92:135–152.

- [18] Li KZ, Roudaia E, Lussier M, Bherer L, Leroux A, McKinley PA. Benefits of cognitive dual-task training on balance performance in healthy older adults. *J Gerontol A Biol Sci Med Sci* 2010;65:1344-52.
- [19] Godin G, Shephard RJ. A simple method to assess exercise behavior in the community. *Can J Appl Sport Sci* 1985;10:141-146.
- [20] A.D. Baddeley., G.J. Hitch, Recent advances in learning and motivation, G.A. Bower ed., New York, New York, 1974.
- [21] M.D. Lezak., D.B. Howieson., E.D. Bigler., D. Tranel, Neuropsychological Assessment, fifth ed., Academic Press, New York, 2012.
- [22] Bernard-Demanze L, Dumitrescu M, Jimeno P, Borel L, Lacour M. Age-related changes in posture control are differentially affected by postural and cognitive task complexity. *Curr Aging Sci* 2009;2(2):139-49.
- [23] Donker SF, Roerdink M, Greven AJ, Beek PJ. Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control. *Exp Brain Res* 2007;181:1-11
- [24] Jehu DA, Paquet N, Lajoie Y. Balance and mobility training with or without concurrent cognitive training improves the timed up and go (TUG), TUG cognitive and TUG manual in healthy older adults. *Aging Clin Exp Res*, Epub ahead of print.
- [25] Lustig C, Shah P, Seidler R, Reuter-Lorenz PA. Aging, training, and the brain: a review and future directions. *Neuropsychol Rev.* 2009;19(4):504-22.
- [26] D. Kahneman, Attention and effort, Englewood Cliffs, New Jersey, 1973.
- [27] Tombu M, Jolicoeur P. Testing the predictions of the central capacity sharing model. *J Exp Psychol Hum Percept Perform* 2005;31,790–802.

[28] Eggenberger P, Schumacher V, Angst M, Theill N, de Bruin ED. Does multicomponent physical exercise with simultaneous cognitive training boost cognitive performance in older adults? A 6-month randomized controlled trial with a 1-year follow-up. *Clin Interv Aging*. 2015;17(10):1335-49.

CHAPTER 7: EXPERIMENT 5**Balance and mobility training with or without simultaneous cognitive training reduces attention demand but does not improve obstacle clearance in older adults**

This article has been submitted to Motor Control. Both Drs. Yves Lajoie and Nicole Paquet give their consent to the inclusion of this manuscript in the current dissertation.

Deborah A.M. Jehu¹, Nicole Paquet², Yves Lajoie^{1*}

1. University of Ottawa, School of Human Kinetics, Ottawa, ON
2. University of Ottawa, School of Rehabilitation Sciences, Ottawa, ON

*Corresponding Author Information:
Yves Lajoie, PhD.
School of Human Kinetics
University of Ottawa
75 Laurier Ave E, Ottawa, ON K1N 6N5
Phone: (613) 562-5800 ext. 4273
Fax: (613) 562-5497
Email: ylajoie@uottawa.ca

ABSTRACT

The purpose was to determine whether balance and mobility training (BMT) or balance and mobility plus cognitive training (BMT+C) would improve obstacle clearance and reaction time (RT); whether further improvements would be exposed in the BMT+C group relative to the BMT group; and whether possible improvements would be sustained at the follow-up. Healthy older adults were allocated to the BMT (n=15; age: 70.2 ± 3.2), BMT+C (n=14; age: 68.7 ± 5.5), or control group (n=13; age: 66.7 ± 4.2). The BMT and BMT+C groups trained one-on-one, 3 times per week for 12 weeks on a balance obstacle course. The BMT+C group also completed cognitive training. Participants walked onto and over 6 obstacles of varying heights while completing no RT, simple RT, and choice RT tasks at baseline, post-training, and at the 12-week follow-up. Both the BMT and BMT+C groups improved RT and maintained these improvements at the follow-up. No meaningful improvements in obstacle clearance emerged following training. Dual-task balance training likely reduces attention demand.

Keywords: balance intervention; cognitive training; dual-tasking; obstacle clearance; reaction time

INTRODUCTION

Tripping is a major concern in the older adult population as it is a main cause of falls (1). Nearly 50% of falls in community-dwelling older adults occur during destabilizing activities such as stepping over obstacles and negotiating raised surfaces (2). Obstacle negotiation involves three main processes: obstacle detection in the environment, processing relevant information, and the execution of an appropriate and timely response (3). It also relies on the availability of sufficient cognitive resources, motor planning, and visually-dependent gait regulation (4). In order to successfully navigate these environments, accommodation strategies are employed and involve the adaptation of the gait pattern for a change in terrain that bring the lower limb to a new-end state, such as requisite with a change in height (e.g., slope, stairs) or physical characteristic in the environment (e.g., type of surface; 5). Obstacle accommodation requires anticipatory locomotor adjustments for the initial change from unobstructed level walking to avoid or accommodate the new environment. Poor obstacle negotiation involves minimal toe clearance accompanied by greater variability of obstacle clearance (6, 7). Empirical evidence reports that as an obstacle height increases, older adults modulate their obstacle crossing strategy to attenuate crossing speed, increase toe and heel clearance, increase the crossing time of the leading limb, and lengthen the swing time of the leading leg (8-11).

Interventions to promote stability during walking have specifically targeted the improvement of obstacle clearance and have shown success in the older adult population (12-14). Recent research has outlined that exercise improves obstacle negotiation strategies, as evidenced by increased toe and heel clearance in older adults (13). Other work has reported significant improvements in gait speed, but no improvements in obstacle negotiation under single or dual-task conditions following group balance training or group balance plus cognitive training in older

adults (15). The training involved balance, gait and agility stations and the cognitive training involved random number generation, word association, backward recitation, and working memory tasks. It is possible that the scarcity of improvements may have stemmed from only 3 hours of training (15). Nevertheless, incorporating cognitive training into balance training interventions has gained significant interest in order to improve attention in older adults.

Attention refers to the capacity or process of receiving, processing, and attending to incoming stimuli (16). Previous research has used the divided attention model to study the impact of attention demand on motor control (17). Compromised concurrent cognitive task performance during obstacle crossing impairs stepping control as observed by increased obstacle contacts in older adults, suggesting that obstacle negotiation stresses the availability of cognitive resources (4, 18). Promising evidence suggests that training cognition may result in improvements in reaction time (RT), working memory, and gross motor skills (19-21). Therefore, divided attention training may be a viable proxy to improve obstacle clearance and attention demand in older adults.

In an attempt to further understand the control mechanisms of dual-task obstacle accommodation following training, the present experiment aimed to determine whether 12 weeks of balance and mobility training (BMT) or 12 weeks of balance and mobility plus cognitive training (BMT+C) would improve obstacle clearance parameters and RT compared to the control group. A second aim was to investigate whether further improvements in obstacle clearance parameters and RT would be shown for the BMT+C compared to the BMT group. The final objective was to examine whether possible improvements from BMT and BMT+C would persist over time at the 12-week follow-up. It was hypothesized that: 1) obstacle clearance parameters and RT would improve after training, as both training programs involved divided attention

training; 2) the BMT+C would introduce further improvements in obstacle clearance parameters and RT compared to the BMT group, as the addition of cognitive training to balance training has promoted improvements in gross motor skills as well as divided attention (19); and 3) possible improvements in obstacle clearance parameters and RT would be sustained at the 12-week follow-up in both training groups because previous work has also observed maintained improvements (22, 23).

METHODS

Participants

Seventy-six older adults were evaluated for eligibility. Inclusion criteria consisted of being 60 years of age and older, having no self-reported musculoskeletal, neurological or sensory deficits that may affect balance, having normal or corrected to normal vision, living independently in the community, walking without an assistive device, obtaining 24 or greater on the Mini-Mental State Examination (MMSE), and being able to discriminate between high and low pitched auditory beeps. Twenty-seven individuals were excluded, 7 did not meet the eligibility criteria and 20 were not interested. Forty-nine healthy older adults were block-randomized by age to the BMT group (n=17; age range: 65-76 years), BMT+C group (n=17; age range: 60-77 years), or the control group (n=15; age range: 62-77 years) (Figure 1). Age was used as a blocking factor in order to control for significant variations in age between groups.

Procedure

The recruitment and data collection of this experiment were conducted from October 2014-February 2016. Participants began the testing session by reading and signing the informed consent form approved by the University of Ottawa Research Ethics Board. To describe the

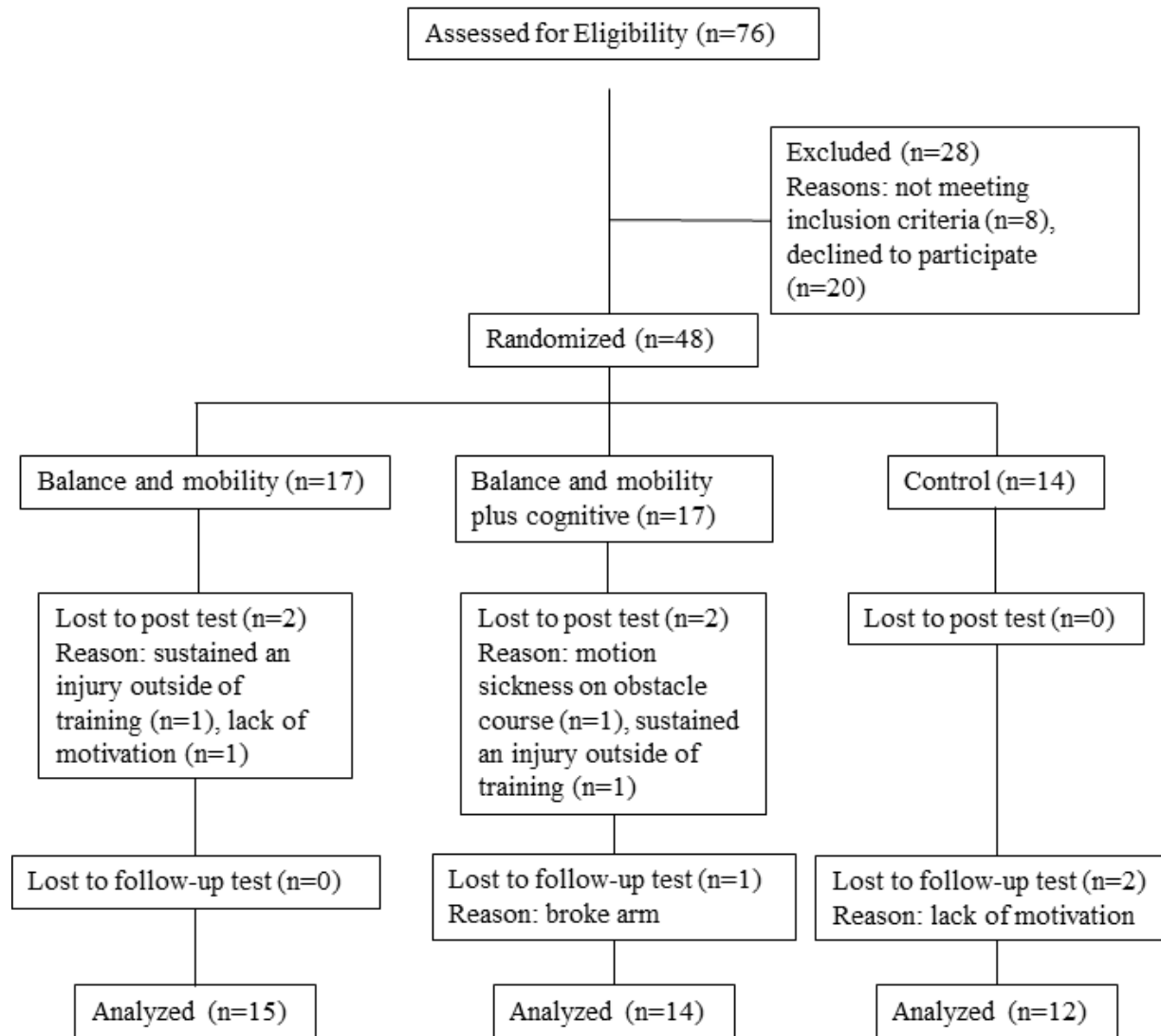


Figure 1. Flow chart of participant recruitment, adherence and attrition.

sample and to rule out other factors that may influence balance, participants completed a demographic questionnaire (i.e., age, sex, education, history of disease, and fall history) as well as the MMSE during the first testing session. The MMSE is an 11-item questionnaire that tests 5 areas of cognitive function: orientation, registration, attention and calculation, recall, and language. The maximum score is 30 and a score of 23 or lower is indicative of cognitive impairment (24). Participant height (cm) and weight (kg) were then measured. Participant characteristics are reported in table 1.

This experiment employed the novel obstacle clearance protocol described in Jehu et al. (25). More specifically, participants crossed a series of 6 obstacles of small, medium and large heights arranged in a mixed order (Figure 2). Participants began with their feet shoulder width apart, took their first step with their self-selected non-dominant foot, and then stepped onto the first obstacle with their dominant foot. Participants were instructed to walk at a comfortable, self-selected pace onto each of the 6 obstacles of varying heights with their dominant foot, and swing over the obstacles with their non-dominant foot across all conditions. Thirty-seven participants chose to step onto the obstacles with their right foot, and 5 with their left. The obstacles were 770 mm in length and 290 mm in width. The height of the obstacles varied such that each obstacle corresponded to a different height from the previous in order to dampen the likelihood of participants adopting an automatic gait pattern. The obstacles were presented in the following order: 100 mm (obstacle 1), 200 mm (obstacle 2), 150 mm (obstacle 3), 200 mm (obstacle 4), 150 mm (obstacle 5), and 200 mm (obstacle 6; Figure 2). Aerobic steppers, which are commonly used in cardiovascular fitness classes, were employed as the obstacles, and one, two, and three risers were utilized, corresponding to the 100 mm, 150 mm, and 200 mm heights.

Table 1Participant characteristics (Mean \pm SD).

Group	Age (years)	Sex (m/f)	Height (cm)	Weight (kg)	Education (years)	MMSE (units)	Godin (MET)	# of Training Sessions Completed
BMT (n=15)	70.2 \pm 3.2	3/12	162.6 \pm 8.9	79.0 \pm 17.9	17.4 \pm 2.8	29.3 \pm 0.8	34.1 \pm 18.0	32.9 \pm 2.6
BMT+C (n=14)	68.7 \pm 5.5	6/9	165.5 \pm 10.7	72.7 \pm 16.4	18.0 \pm 2.4	29.7 \pm 0.5	34.3 \pm 24.0	34.5 \pm 2.3
Control (n=13)	66.3 \pm 4.4	3/9	166.3 \pm 9.1	72.5 \pm 13.8	18.5 \pm 2.6	29.1 \pm 1.5	34.5 \pm 15.8	NA

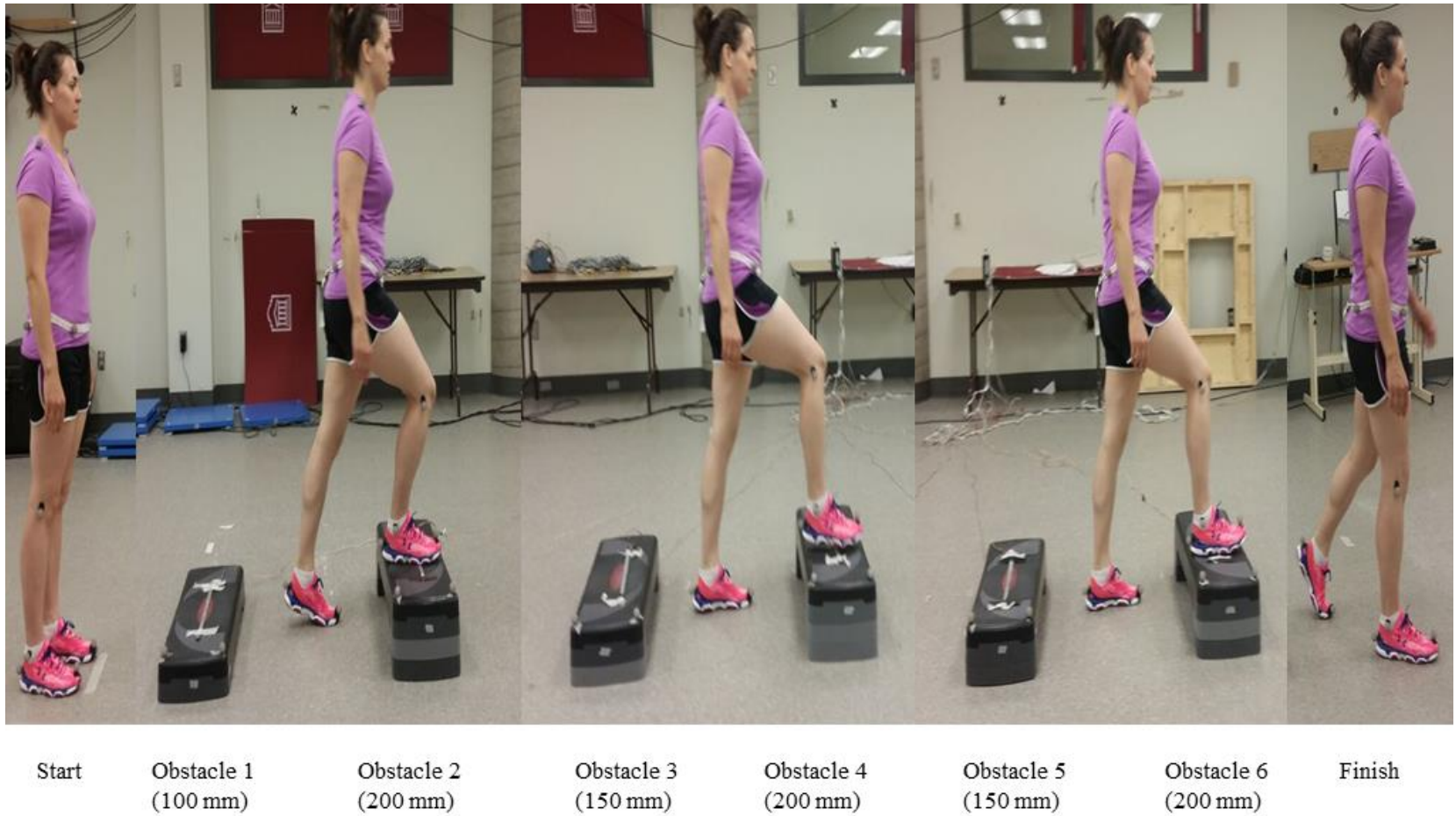


Figure 2. Diagram of 6 obstacles of varying heights with foot-switches triggering auditory stimuli.

A foot-switch was placed onto each of the obstacles, and was used to trigger the auditory stimuli. Participants self-selected whether the obstacles would be spaced at a small (460 mm), medium (690 mm), or large (920 mm) distance apart by attempting the various distances and selecting the most comfortable. Six participants chose the small, 35 participants chose the medium, and 1 participant chose the large distance between obstacles. The exact walking path was 5490 mm for the small, 6870 mm for the medium, and 8250 mm for the large distance between obstacles. All participants took 14 steps.

Reflective markers were placed on both sides of participant on the calcaneus and first metatarsal. The time to completion of stepping onto and over the 6 obstacles was measured from the onset of movement during feet apart to two steps after the last obstacle. Minimum foot clearance was calculated by taking the minimum vertical distance between the dominant toe as well as the swing toe leading up to the anterior side of the obstacle, as well as the lowest point between the trailing swing heel and the posterior side of the obstacle. A marker was placed on the anterior and posterior edges of each obstacle, and was used to calculate clearance. None of the participants tripped during the experimental protocol.

Participants were asked to walk onto and over the obstacles while completing no RT, simple reaction time (SRT), and choice reaction time (CRT) tasks. The auditory stimuli were randomly presented upon foot strike of the dominant foot on the foot-switches placed on each obstacle. Therefore, all auditory stimuli were administered during double-leg stance. During the SRT trials, participants were asked to verbally respond “tie” to high pitched auditory cues that were randomly administered throughout the trials. Between 1 and 4 stimuli were presented per trial. During the CRT trials, participants were presented with random high and low auditory stimuli and were asked to respond “tie” and “tow”, respectively. These words were chosen as

they have a hard consonant and they also resemble the words “high” and “low”, which were the two different pitches used. Between 2 and 4 stimuli were administered per trial. If participants incurred one or more errors of omission or commission in a single trial, the trial was repeated. In total, 17 experimental trials were completed per session including: 3 control trials (i.e., no RT), 6 SRT, and 8 CRT. Prior to the experimental conditions, a familiarization period was performed including 3 seated SRT and CRT 30 s trials as well as 1 trial of walking over the obstacles without auditory stimuli at the beginning of each testing session.

Data analyses

A 3D 8-camera Vicon 512 motion analysis system (Oxford Metrics, Tustin, CA, USA) was used to capture the position of the markers at a sampling frequency of 200 Hz. Kinematic data were analyzed to obtain toe and heel clearance over each obstacle, and time to completion.

An mp3 recorder (Sony MP3 IC Recorder (ICD-UX70), San Diego, CA) was attached to the participants' left arm and used to capture both the high and low auditory stimuli emitted by a piezoelectric speaker and the verbal responses in order to determine RT. The high-pitched signal was administered at a fixed frequency of 2850 Hz at an intensity of 99 dB, whereas the low-pitched signal was administered at a fixed frequency of 970 Hz at an intensity of 95 dB for approximately 100 ms. The Audacity software system was used to process RT, which was computed manually through visual inspection using vertical cursors from the start of the verbal response minus the onset of the auditory cue in seconds.

Intervention

The intervention procedure has been previously reported (26, 27). The training took place at the University of Ottawa in an exercise room. Participants in the BMT and BMT+C groups trained one-on-one for 1 hour, 3 times per week for 12 weeks with a trainer. The warm-up

consisted of walking at a self-selected pace on a treadmill for 5 minutes, followed by 8 flights of stairs. Participants then completed approximately 50 minutes of static and dynamic exercises on a variety of unstable objects on the balance obstacle course (Table 2; Appendix 1). For example, center of mass (COM) and base of support (BOS) perturbations on the both sides up (BOSU) ball, walking in tandem along half foam rollers, weaving around foam rollers when walking across balance pods, balancing on a square or circular wobble board arranged in the medial-lateral (ML), anterior-posterior, or diagonal direction, trunk stability exercises on a chair or stability ball, and random changes in walking direction. While participants were negotiating the obstacle course, they also completed a second task, such as: holding a bin, moving a medicine ball up and down, moving a ball around the body, bouncing a ball, and catching and throwing a bean bag. The training program was progressive such that as participants improved, the physical exercises as well as the second tasks became more difficult. For example, the level of difficulty of the exercises on the obstacle course was altered by manipulating BOS, perturbing the COM and/or BOS, and changing the direction of tilt of the wobble board. The difficulty of the second task was altered by adding weight to an object, completing the task faster, and changing a clear object to an opaque object to partially occlude vision, for example (Appendix 2). In order for the trainer increase the fixed level of difficulty in the next session, the participant must have successfully completed the exercise without losing their balance (e.g., stepping out of tandem, or using the wall or the trainer as a support). The training programs were individualized because each participant progressed at their own pace. Finally, participants stretched all major muscle groups while balancing for 2 minutes.

The BMT+C group also performed 13 different cognitive tasks that were associated with

Table 2

Description of movements and activities of level 1 of the balance obstacle course, associated cognitive tasks, and levels attained following training.

Obstacle Course Exercises	Balance Training Level of Difficulty Attained After BMT	Balance Training Level of Difficulty Attained After BMT+C	Cognitive Task Exercises	Cognitive Training Level of Difficulty Attained After BMT+C
Step over a skip rope in the medial-lateral direction	8.00 ± 2.45	7.93 ± 2.02	N-back numbers *#	4.50 ± 2.28
Reach laterally high and low on a foam surface with feet together	12.19 ± 4.48	8.86 ± 2.74	Letter sequencing *#	6.29 ± 4.08
Stand on two balance disks with feet apart	4.00 ± 0.73	3.36 ± 0.63	Number sequencing *#	5.64 ± 3.03
Step and turn 360 ° on the BOSU	4.81 ± 1.56	4.36 ± 1.22	N-back words *#	5.50 ± 3.59
Stand on a firm surface with feet together while pulling elastic bands	17.00 ± 4.23	12.43 ± 4.18	Counting backwards † Θ	7.50 ± 5.16
Walk in tandem along a taped path	14.75 ± 6.17	9.71 ± 4.10	Conversation and description on request †+	3.14 ± 0.86
Stand on foam with feet apart	6.06 ± 0.92	6.00 ± 2.82	Arithmetic operations * •	2.57 ± 0.65
Stand with one foot on the square wobble board oriented in the medial-lateral direction and one foot on the balance disk	6.38 ± 2.92	5.64 ± 1.74	Spelling to dictation *°	6.43 ± 3.52
Rotate around the perimeter edges	3.94 ± 1.00	3.21 ± 0.89	Oral spelling †°	2.93 ± 1.77

of the circular wobble board in both directions				
Step onto and off of the stepper in the anterior-posterior direction	10.25 ± 2.49	7.86 ± 1.96	Counting forwards † Θ	7.50 ± 5.16
Side step along half foam rollers	3.88 ± 1.86	2.64 ± 1.01	Number lists *§	5.29 ± 2.76
Walk across staggered balance pods	3.63 ± 1.09	3.00 ± 0.68	Naming †+	2.79 ± 1.53
Seated in a chair, pick up a ball from the ground on one side and move it to the ground on the other side with feet lifted	8.31 ± 2.94	7.14 ± 2.28	Math fluency † •	3.50 ± 1.22
Average ± SD	7.94 ± 1.85	6.32 ± 1.29	NA	4.89 ± 2.07

* Represents tasks performed with auditory recording; † represents tasks performed without auditory recording; The following neuropsychological categories and subcategories were trained # Orientation and Attention: Working Memory/Mental Tracking; Θ Verbal Memory: Verbal Automatism; + Verbal Function and Language Skills: Discourse; • Concept Formation and Reasoning: Mathematical Procedures; ° Verbal Functions and Language Skills: Verbal Academic Skills; § Memory: Verbal Memory.

the respective balance task on the obstacle course that challenged the phonological loop and central executive components of the working memory model (28). These cognitive tasks were chosen as they did not include a visual component since vision was required during the balance and manual task training. They were also chosen as they were all continuous cognitive tasks that constantly demanded attention. The majority of the cognitive tasks were made incrementally more difficult by completing the task faster, adding memorization, reciting a list in alphabetical order forwards (i.e., starting with words that begin with “a”) or backwards (i.e., starting with words that begin with “z”). Participants advanced on the same levels when there were no mistakes or breaks in speech (i.e., <3-5 s; Appendix 3). Table 2 highlights the specific neuropsychological processes that were trained for each cognitive task (29).

Following the 12-week training, participants in the BMT and BMT+C groups were encouraged to stay physically active. They were informed of a free, city-funded exercise program, and if this did not suit their interests, they were encouraged to find some form of physical activity to engage in. Participants in the control group were asked to keep their lifestyle the same throughout the study, but were encouraged to be physically active at the 12-week follow-up session.

The control group was asked not to alter their daily routine during the experiment. Blinding of investigators was not possible because the investigators supervised and conducted the training sessions.

Adherence

Adherence was examined by assessing the mean number of sessions attended out of a total of 36 one-hour sessions. Participants must have attended 29/36 sessions (i.e., 80% adherence rate), otherwise they would be excluded from the analysis.

Statistical analyses

To address whether balance training improved obstacle clearance across various obstacle heights, separate three-way analyses of variance (ANOVAs) were performed on Group (BMT group, BMT+C group, control group) x Session (Baseline, Post-training, Follow-up) x Obstacle (1 to 6), with repeated measures on the clearance of the mean and standard deviation (SD) of the leading toe of the swing leg, mean and SD of the leading toe of the dominant leg, and the mean and SD of the trailing heel of the swing leg.

In order to determine whether balance training improved obstacle clearance parameters across dual-task conditions, separate three-way ANOVAs were performed on Group (BMT group, BMT+C group, control group) x Session (Baseline, Post-training, Follow-up) x RT difficulty (no RT, SRT, CRT) with repeated measures on each factor for the clearance of the mean and SD of the leading toe of the swing leg, mean and SD of the leading toe of the dominant leg, mean and SD of the trailing heel of the swing leg, and mean and SD of the time to completion of the series of 6 obstacles.

In order to determine whether balance training improved RT, separate three-way repeated measures analyses of variance (ANOVAs) were performed on Group (BMT group, BMT+C group, control group) x Session (Baseline, Post-training, Follow-up) x RT difficulty (SRT, CRT) with repeated measures on each factor for the mean and SD of SRT and CRT.

When applicable, post hoc least significant difference comparisons were performed. If Mauchly's test of Sphericity was violated, the Greenhouse-Geisser correction was performed. Statistical significance was set to $p < 0.05$.

RESULTS

Baseline obstacle clearance parameters and RT characteristics between groups

There were no differences in obstacle clearance or RT parameters between groups at baseline ($p>0.05$).

Effect of balance training on balance and cognition

Table 2 presents the final balance training level achieved on each of the static and dynamic exercises on the obstacle course following BMT and BMT+C. It also outlines the final cognitive training level achieved on each of the cognitive exercises completed while negotiating the obstacle course following BMT+C.

Effect of balance training on obstacle clearance parameters

The significant Group by Session Interaction effect for the SD of the dominant leading toe ($F_{(4,76)}=3.65, p<0.05, \eta^2=0.16$) revealed less variability of the dominant leading toe following BMT compared to baseline, and less variability at the follow-up compared to baseline and post training ($p<0.05$), while no differences emerged for the BMT+C ($p>0.05$) or control group ($p>0.05$; Table 3).

No Group by Session Interaction effects were observed for the mean swing leading toe ($F_{(4,76)}=0.92, p>0.05$), SD swing leading toe ($F_{(4,76)}=0.40, p>0.05$), mean dominant leading toe ($F_{(4,76)}=1.33, p>0.05$), mean trailing heel clearance ($F_{(4,76)}=1.66, p>0.05$), SD trailing heel clearance ($F_{(4,76)}=0.79, p>0.05$), mean time to completion ($F_{(4,76)}=0.94, p>0.05$) or SD time to completion ($F_{(4,76)}=0.60, p>0.05$).

The main effect of Session ($F_{(2,76)}=8.65, p<0.05, \eta^2=0.19$) for the SD dominant leading toe such that participants exhibited greater variability of the dominant leading toe clearance at baseline compared to post training ($p<0.05$) and follow-up ($p<0.05$), with no differences between

post training and follow up ($p>0.05$). The main effect of Session ($F_{(2,76)}=4.66$, $p<0.05$, $\eta^2=0.11$) for mean heel clearance revealed that participants increased mean heel clearance at post-training ($p<0.05$) and follow-up ($p=0.061$) compared to baseline. The main effect of Session for mean time to completion ($F_{(2,24)}=10.20$, $p<0.05$, $\eta^2=0.46$) revealed that participants walked significantly faster post-training compared to baseline ($p<0.05$), and significantly faster at the follow-up compared the baseline ($p<0.05$; Table 3).

No main effect of Session emerged for the mean swing leading toe ($F_{(2,76)}=2.59$, $p>0.05$), SD swing leading toe ($F_{(2,76)}=1.41$, $p>0.05$), mean dominant leading toe ($F_{(2,76)}=1.86$, $p>0.05$), or SD trailing heel clearance ($F_{(2,76)}=0.13$, $p>0.05$), SD time to completion ($F_{(2,24)}=0.07$, $p>0.05$).

Effect of balance training on RT

There was a significant Group by Session interaction for mean RT ($F_{(2, 44)}=7.49$, $p<0.05$, $\eta^2=0.41$; Figure 3a). Post hoc analyses revealed that both the BMT and BMT+C groups showed significantly faster SRT and CRT post-training compared to baseline ($p<0.05$), faster SRT and CRT at the follow-up compared to baseline ($p<0.05$), and no differences between post-training and follow-up sessions ($p>0.05$). No differences in mean RT across sessions were displayed for the control Group ($p>0.05$).

There was a significant Group by Session interaction for SD of RT ($F_{(2, 44)}=2.95$, $p<0.05$, $\eta^2=0.21$; Figure 3b). Post hoc analyses exposed significantly reduced SD CRT post-training compared to baseline ($p<0.05$), reduced SD CRT at the follow-up compared to baseline ($p<0.05$), and no differences in SD CRT between post-training and follow-up sessions, or in SD SRT across sessions for the BMT group ($p>0.05$). The BMT+C group showed significantly reduced SD CRT post-training compared to baseline ($p<0.05$), a trend for reduced SD CRT at the follow-up compared to baseline ($p=0.056$), and no differences between post-training and follow-up

Table 3Mean \pm SD (mm) of the BMT, BMT+C, and Control groups over time.

	Baseline			Post-Training			Follow-Up		
	BMT	BMT+C	Control	BMT	BMT+C	Control	BMT	BMT+C	Control
Swing leading toe (mm)	83.48 \pm 10.25	82.29 \pm 9.02	93.11 \pm 10.87	86.74 \pm 9.35	85.27 \pm 8.99	90.26 \pm 9.08	87.41 \pm 10.35	86.61 \pm 9.01	96.48 \pm 9.37
Dominant leading toe (mm) †	92.10 \pm 9.90	100.35 \pm 9.06	100.47 \pm 9.25	92.04 \pm 8.40	100.00 \pm 8.88	96.26 \pm 7.99	91.51 \pm 7.59	100.12 \pm 8.22	90.00 \pm 8.51
Swing trailing heel (mm) *	75.36 \pm 10.29	79.24 \pm 10.21	82.93 \pm 9.55	92.08 \pm 8.90	81.30 \pm 10.93	89.64 \pm 9.39	93.39 \pm 9.72	79.24 \pm 9.64	84.05 \pm 9.89
Time to completion (s) §	9.17 \pm 0.46	8.40 \pm 0.32	8.79 \pm 0.33	8.54 \pm 0.39	7.78 \pm 0.36	8.33 \pm 0.35	8.44 \pm 0.30	7.62 \pm 0.30	8.35 \pm 0.24
Estimated COM variability in the ML (mm) Θ	79.65 \pm 16.51	68.26 \pm 15.47	77.76 \pm 13.15	102.19 \pm 17.73	83.40 \pm 19.41	86.04 \pm 18.06	106.65 \pm 17.53	71.18 \pm 16.01	84.73 \pm 13.84

† Represents significantly less SD of the dominant leading toe for the BMT group at post-training compared to baseline, and less at the follow-up compared to baseline ($p < 0.05$); *represents significantly less mean heel clearance at baseline compared to post-training and follow-up ($p < 0.05$); § represents significantly longer mean time to completion at baseline compared to post-training and follow-up ($p < 0.05$); Θ represents significantly less estimated SD of the COM variability in the medial-lateral (ML) direction at baseline compared to post-training ($p < 0.05$).

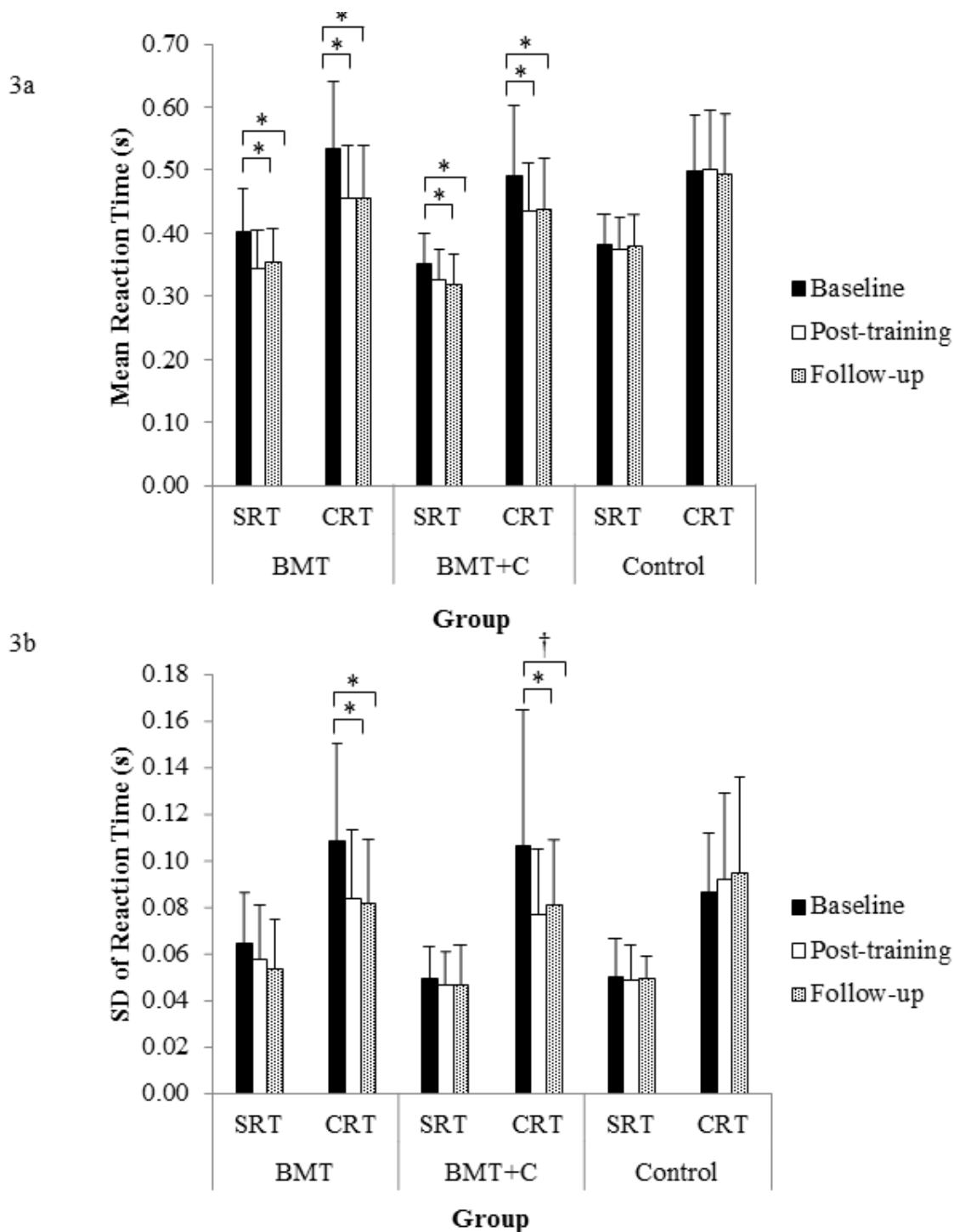


Figure 3a. Average (+ 1 SD) of simple reaction time (SRT) and choice reaction time (CRT) for the balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and control groups at baseline, post-training, and 12-week follow-up. * $p < 0.05$; 3b. SD (+ 1 SD) of simple reaction time (SRT) and choice reaction time (CRT) for the balance and mobility training (BMT), balance and mobility plus cognitive training (BMT+C), and control groups at baseline, post-training, and 12-week follow-up. * $p < 0.05$; † $p = 0.056$.

sessions, or in SD SRT across sessions ($p>0.05$). No differences in the SD of RT across sessions emerged for the control group ($p>0.05$).

DISCUSSION

Main findings

This experiment found 1) significantly faster RT following BMT and BMT+C, while there were no differences in the control group; significantly decreased variability of the dominant leading toe clearance in the BMT group only, as well as significantly reduced time to completion across all groups; 2) no further improvement in obstacle clearance parameters or RT in the BMT+C group compared to the BMT group; and 3) that improvements in RT were sustained at the follow-up for both the BMT and BMT+C groups, while no changes were observed in the control group.

Effect of balance training on obstacle clearance parameters

The present experiment demonstrated little changes in obstacle clearance parameters across various obstacle heights or across RT conditions following BMT or BMT+C. Few experiments have explored the effects of training on obstacle clearance parameters in older adults. Some research has shown greater clearance over obstacles following aquatic (13) and strength (12) training, and suggests that participants adopt a more cautious crossing strategy, thereby enabling a safer clearance and decreasing the likelihood of tripping. Contrarily, no significant improvements in obstacle negotiation have been reported following group balance training or group balance plus cognitive training in older adults (15). Other work has revealed greater obstacle clearance in older adults who engage in tai chi compared to older adult walkers (30), which assimilates that the type of exercise may modulate the selected strategy for obstacle crossing. We found that even with 12 weeks of training, there were no significant differences in

obstacle clearance parameters. The conflicting findings as to whether training induces improvements in obstacle negotiation may stem from differences in the type of intervention implemented (e.g., aquatic, balance plus cognitive, strength training); the outcome measures selected (e.g., obstacle clearance, gait speed, stride length); the length of the intervention (e.g., 3 hours-24 weeks), the precision of the measuring tool (e.g., force platform, motion capture, stop watch), and the cognitive resources utilized (e.g., motor planning, verbal automatisms, discourse; 12, 13, 15, 30).

The current obstacle negotiation task was relatively constrained in that little choice in stride length and foot placement on and between the obstacles could occur such that a foot placed too far forward on the step would risk being in an awkward position for clearing the second step during the subsequent swing phase. As such, the present protocol may have been even more difficult as it involved dual-tasking while negotiating a series of obstacles and therefore may have required more information processing requirements compared to previous work examining one obstacle crossing during single-tasking (12, 13, 30).

Although the decreased variability of clearance of the dominant leading toe following BMT reached statistical significance, the 1.5 mm change from baseline to post-training was likely not a meaningful improvement (Table 3). Previous work has not examined training-related changes in the variability of obstacle clearance, however meaningful improvements in the mean step clearance range from an increase of 86 mm for toe clearance and 169 mm for heel clearance after aquatic training compared to baseline (13), while no improvements in mean obstacle clearance were observed in the present experiments. Given that the toe and heel clearances at baseline across groups were similar to previously reported safe obstacle crossing values (31); it is

possible that obstacle clearance was already adequately high, leaving little room for training-related improvements to occur in the present experiment.

The BMT, BMT+C and control groups all exhibited faster time to completion of the obstacle negotiation at the post-test. Faster gait speed has been a hallmark of training (32); nevertheless, our findings do not present training-related improvements in obstacle clearance parameters. Previous work in our lab suggests that the improvements in walking speed may be a function of repeated exposure to the testing protocol as improved mean and variability of the time to completion appeared after 1 repeated testing session in healthy older adults (25). Consequently, the increased heel clearance observed across all groups may have occurred as a function of the increased walking speed. Despite the lack of training-related improvements in obstacle clearance, previous research reports significant improvements in functional mobility as measured by the timed up & go (26), but no improvements in posture as measured through center of pressure measures (27) following BMT and BMT+C training. Therefore, this suggests that BMT and BMT+C may elicit task-specific improvements.

Effect of balance training on RT

Significant improvements in RT were delineated in both the BMT and BMT+C groups while there were changes found in the control group. These improvements were also sustained at the follow-up. This experiment reveals that both training groups effectively allocated more resources to the RT task, resulting in faster RTs, without compromising the obstacle negotiation task. The task prioritization model suggests that improvements in performance can be shown in either or both tasks (33), which may explain the improvements in RT but not obstacle clearance parameters following training. Previous work has shown no improvements in dual-tasking during obstacle negotiation following balance or balance plus cognitive training; however, participants

only received 3 hours of training (15). Our findings lend to reason that 12 weeks of BMT and BMT+C results in less dual-task interference between the information processing of the RT task and obstacle negotiation relative to the control group. Therefore, divided attention training may be an effective method for improving attention demand in a locomotion context in older adults.

The BMT and BMT+C groups presented faster SRT and CRT relative to the control group. Appendix 4 compares the effects of repeated exposure of RT during the obstacle clearance protocol at baseline (BMT, BMT+C, Control, and Preliminary Study 2), and after 12-weeks (BMT, BMT+C, and Control) or after 5 repeated testing sessions (Study 2). According to Appendix 4, the repeated exposure to RT led to faster CRT during obstacle negotiation compared to the BMT, BMT+C and control groups. It may be reasonable to believe that these improvements may have been a function of gaining further exposure to the specific outcome measures included in testing protocols of Studies 1-3, as they were all performed within the same session. Notably, the control group exhibited no repeated testing effects on RT, likely because they were only tested 3 times in 6 months, while the preliminary study group was tested 5 times within 5 weeks. This indicates that attention demand may be sensitive to repeated administration effects when the testing sessions are close in proximity. Thus, the improvements in RT exposed in the BMT and BMT+C groups are likely a function of dual-task training instead of the repeated testing.

Previous research reports that training cognition can improve cognitive skills (19). Since the BMT+C group elicited improvements on the level of difficulty of the cognitive training exercises as reported in table 2, we were surprised that no differences in attention demand emerged between the BMT and BMT+C groups. In fact, the BMT group achieved 1.6 levels greater than the BMT+C group on the balance exercises. Perhaps concurrently performing

balance, manual and cognitive tasks restrained the rate of improvement on the obstacle course in the BMT+C group. Notwithstanding, perhaps the additional cognitive training that the BMT+C group received acted as a compensation, thereby improving the ability to concurrently perform multiple tasks and leading to similar improvements in RT relative to the BMT group. Therefore, these results suggest that heightened attention demand during training promotes reduced attention demand. These findings are in line with previous work reporting reduced attention demand during standing postural control following BMT and BMT+C (27).

Importantly, this experiment reveals that 12 weeks following the arrest of training, participants in the BMT and BMT+C maintained their improvements in RT, while no improvements were presented in the control group. Our results are in line with previous research that elicited significant improvements in cognition following 2 weeks of cognitive training during bedrest in older adults, and sustained improvements after a 400-day follow-up (23). These findings emphasize the integrity of cognitive training as despite the negative effects of bedrest, participants still improved and sustained cognitive training effects. Greater attention demand has been documented to increase falls (34). To this end, interventions to reduce attention demand, like BMT and BMT+C, should be implemented in the older adult population.

Limitations

There are a few limitations that should be taken into consideration. Firstly, the experiment may have needed a larger sample size to show significant differences between groups. Because a new testing protocol was implemented, it may require further investigation in order to determine the most sensitive outcome measures. Lastly, the training programs included a wide variety of balance and cognitive tasks; therefore, participants may have had less opportunity to improve on any given skill.

CONCLUSION

In conclusion, no meaningful improvements in obstacle clearance parameters emerged following training. The BMT and BMT+C groups significantly reduced attention demand after training, and preserved these improvements at the 12-week follow-up. No differences between training groups appeared in obstacle clearance parameters or RT. These findings are important for clinicians and researchers as BMT and BMT+C equally contributed to improved attention demand and sustained improvement at the follow-up in healthy older adults.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

ACKNOWLEDGEMENTS

This project was financed by an internal grant from the University of Ottawa.

REFERENCES

1. Berg WP, Alessio HM, Mills EM, Tong C. Circumstances and consequences of falls in independent community-dwelling older adults. *Age Ageing*. 1997;26:261–268.
2. Tinetti M, Doucette J, Claus E, Marottoli R. Risk factors for serious injury during falls by older persons in the community. *J Am Geriatr Soc*. 1995;43:1214-1221.
3. Mohagheghi AA, Moraes R, Patla AE. The effects of distant and on-line visual information on the control of approach phase and step over an obstacle during locomotion. *Exp Brain Res*. 2004;155(4):459–468.
4. Brown LA, McKenzie NC, Doan JB. Age-dependent differences in the attentional demands of obstacle negotiation. *J Gerontol A Biol Sci Med Sci*. 2005;60:924–927.
5. McFadyen BJ, Carnahan H. Anticipatory locomotor adjustments for accommodating versus avoiding level changes in humans. *Exp Brain Res*. 1997;114(3):500-506.
6. Barrett RS, Mills PM, Begg RK. A systematic review of the effect of ageing and falls history on minimum foot clearance characteristics during level walking. *Gait Posture*. 2010;32:429–435.
7. Begg RK, Best R, Dell’Oro L, Taylor S. Minimum foot clearance during walking: strategies for the minimisation of trip-related falls. *Gait Posture*, 2007;25:191-198.
8. Austin GP, Garrett GE, Bohannon RW. Kinematic analysis of obstacle clearance during locomotion. *Gait Posture*. 1999;10:109–120.
9. Chen HC, Ashton-Miller JA, Alexander NB, Schultz AB. Stepping over obstacles: gait patterns of healthy young and old adults. *J Gerontol A Biol Sci Med Sci*. 1991;46:M196–203.

10. Pan HF, Hsu HC, Chang WN, Renn JH, Wu HW. Strategies for obstacle crossing in older adults with high and low risk of falling. *J Phys Ther Sci.* 2016;28(5):1614-1620.
11. Sparrow WA, Shinkfield AJ, Chow S, Begg RK. Characteristics of gait in stepping over obstacles. *Hum Mov Sci.* 1996;15:605–622.
12. Lamoureux E, Sparrow WA, Murphy A, Newton RU. The effects of improved strength on obstacle negotiation in community-living older adults. *Gait Posture.* 2003;17:273-283.
13. Lim HS, Yoon S. The influence of short-term aquatic training on obstacle crossing in gait by the elderly. *J Phys Ther Sci.* 2014;26:1219–1222.
14. Weerdesteyn V, Rijken H, Geurts AC, Smits-Engelsman BC, Mulder T, Duysens J. A five-week exercise program can reduce falls and improve obstacle avoidance in the elderly. *Gerontol.* 2006;52:131-141.
15. Plummer-D'Amato P, Cohen Z, Daece NA, Lawson SE, Lizotte MR, Padilla A. Effects of once weekly dual-task training in older adults: A pilot randomized controlled trial. *Geriatr Gerontol Int.* 2012;12:622–629.
16. Parasuraman, R. The attentive brain: Issues and prospects. In R. Parasuraman (Ed.), *The attentive brain.* Cambridge, MA: MIT Press; 1998.
17. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: A review of an emerging area of research. *Gait Posture.* 2002;16:1-14.
18. Chen HC, Schultz AB, Ashton-Miller JA, Giordani B, Alexander NB, Guire KE. Stepping over obstacles: dividing attention impairs performance of old more than young adults. *J Gerontol A Biol Sci Med Sci.* 1996;51:116–122.

19. Li KZ, Roudaia E, Lussier M, Bherer L, Leroux A, McKinley PA. Benefits of cognitive dual-task training on balance performance in healthy older adults. *J Gerontol A Biol Sci Med Sci.* 2010;65:1344-1352.
20. Stobach T, Frensch P, Hermann M, Schubert T. Age- and practice-related influences on dual-task costs and compensation mechanisms under optimal conditions of dual-task performance. *Aging Neuropsychol Cogn.* 2012;19:222-247.
21. Stobach T, Frensch P, Hermann M, Schubert T. Testing the limits of optimizing dual-task performance in younger and older adults. *Front Hum Neurosci.* 2012;6:1-12.
22. Lim HS, Yoon S. The training and detraining effects of 8 weeks of water exercise on obstacle avoidance in gait by the elderly. *J Phys Ther Sci.* 2014;26:1215–1218.
23. Marusic U, Giordani B, Moffat SD, Petrič M, Dolenc P, Pišot R, Kavcic V. Computerized cognitive training during physical inactivity improves executive functioning in older adults. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn.* 2016;Dec 12:1-21. Epub ahead of print
24. Folstein M, Folstein SE, McHugh PR. Mini-mental state a practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res.* 1975;12:189-198.
25. Jehu DA, Lajoie Y, Paquet, N. Improvements in obstacle clearance parameters and reaction time over a series of obstacles revealed after 5 repeated testing sessions in older adults. *Motor Control.* (In Review).
26. Jehu DA, Paquet N, Lajoie Y. Balance and mobility training with or without concurrent cognitive training improves the timed up & go (TUG), TUG cognitive and TUG manual in healthy older adults. *Aging Clin Exp Res.* 2016;Aug 18, Epub ahead of print.

27. Jehu DA, Paquet N, Lajoie Y. Balance and mobility training with or without concurrent cognitive training does not improve posture but improves reaction time in healthy older adults. *Gait Posture*. 2017;52:227-232.
28. Baddeley AD, Hitch GJ. Recent advances in learning and motivation, G.A. Bower ed., New York, New York; 1974.
29. Lezak, MD, Howieson DB, Bigler ED, Tranel D. (2012). *Neuropsychological Assessment*, fifth ed., Academic Press, New York; 2012.
30. Zhang C, Mao D, Riskowski JL, Song Q. Strategies of stepping over obstacles: The effects of long-term exercise in older adults. *Gait Posture*. 2011;34:191–196.
31. Chou L, Draganich LF. Placing the trailing foot closer to an obstacle reduces flexion of the hip, knee, and ankle to increase the risk of tripping. *J Biomech*. 1998;31:685–691.
32. Hortobagyi T, Lesinski M, Gabler M, Jessie M, VanSwearingen JM, Malatesta D, Granacher U. Effects of three types of exercise interventions on healthy old adults' gait speed: A systematic review and meta-analysis. *Sport Med*. 2015;45:1627–1643.
33. Tombu M, Jolicoeur P. Testing the predictions of the central capacity sharing model. *J Exp Psychol Hum Percept Perform*. 2005;31:790–802.
34. Makizako H, Furuna T, Shimada H, Ihira H, Kimura M, Uchiyama E, Oddsson LI. Association between a history of falls and the ability to multi-task in community dwelling older people. *Aging Clin Exp Res*. 2010;22(5-6):427-432.

CHAPTER 8: GENERAL DISCUSSION

Summary of the main findings

The first objective of this thesis was to determine whether dual-task training-related improvements could be attributed to the interventions themselves, as opposed to the repeated exposure to the testing protocol in older adults. The second purpose was to establish whether 12 weeks of balance and mobility training (BMT) or balance and mobility plus cognitive training (BMT+C) would result in improvements in postural sway, functional mobility, obstacle clearance, and attention demand compared to the control group in older adults. A third aim was to determine whether further dual-task training-related improvements would be exhibited in the BMT+C group relative to the BMT group. The last goal was to determine whether possible improvements from BMT and BMT+C in postural sway, functional mobility, obstacle clearance, and attention demand would be sustained at the 12-week follow-up compared to the control group. In general, the main findings from the first objective were that: no differences in any of the posturographic measures or timed-up & go (TUG), TUG cognitive (TUGcog) or TUG manual (TUGman) emerged over the 5 testing sessions; longer and less consistent time to completion over the obstacle series were observed in session 1 compared to sessions 2-5; no changes in simple reaction time (SRT) appeared after repeated exposure during the standing protocol, but choice reaction time (CRT) improved after serial administration of the testing protocol; and during obstacle negotiation, improvements in SRT were displayed after session 2, while CRT gradually improved and did not reach a plateau after repeated testing. Secondly, BMT and BMT+C elicited: no significant improvements in postural sway; significant improvements in all TUG measures; no meaningful improvements in obstacle clearance; and SRT and CRT significantly improved during the standing and obstacle clearance protocols, while

no differences emerged for the control group. The results from the third aim showed no differences across any of the outcome measures between the BMT and BMT+C groups. Lastly, improvements in functional mobility and attention demand during the standing and obstacle clearance protocols were sustained in the BMT and BMT+C groups at the follow-up, while no differences emerged for the control group.

Effects of repeated exposure to the testing protocol on postural sway, functional mobility, obstacle clearance parameters and attention demand (Research Question 1)

No differences in any of the posturographic measures over the 5 testing sessions under single and dual-task contexts were realized in older adults (Study 1), which confirms previous findings in young adults (Diamentopoulos, Clifford, & Birchall, 2003; Geurts, Nienhuis, & Mulder, 1993). However, other work has prompted differences in sway parameters across repeated testing procedures in young adults (Elliott & Murray, 1998), but these changes may be due to differences in instruction. For example, Elliott and Murray (1998) asked participants to lock the knees during the standing trials, which potentially promoted an internal focus of attention and led to a conscious control of posture (Wulf, Weigelt, Poulter, McNevin, 2003). This may have inherently introduced greater variability and may have produced differences across sessions. Another study demonstrated that repeated exposure effects on postural sway parameters were heightened with increased difficulty of the postural task (e.g., eyes open firm surface compared to eyes closed on foam surface), and when the time interval between testing sessions was shortened (i.e., 11 days relative to 17, 31, and 115 days; Nordahl, Aasen, Dyrkorn, Eidsvik, & Molvaer, 2000). Therefore, these findings highlight the importance for consistency of instructions across studies as well as a familiarization period of adequate length (e.g., sufficient practice trials in order to diminish the likelihood of learning effects).

The TUG, TUGcog, and TUGman attested to be stable across the 5 repeated testing sessions administered once per week for 5 weeks in older adults (Study 3). Additionally, no differences in functional mobility were observed in the control group, who were tested 3 times over 6 months. This was the first study to determine and compare the repeatability of the three TUG measures. These findings suggest that improvements in functional mobility following an intervention are likely attributable to the training itself, as opposed the repeated administration of the testing protocol.

Most obstacle clearance parameters were stable across the 5 repeated testing sessions (Study 2). However, longer and less consistent time to completion of the obstacle series were observed in session 1 compared to sessions 2-5. The practice-induced improvements in the mean and variability of the time to completion suggest that older adults became more efficient and consistent after repeated testing due to learning. Older adults adopted a cautious strategy during session 1, perhaps because they were not confident and accustomed to the testing environment. These findings agree with previous work revealing significantly faster walking speed across a number of gait tasks in a control group who was tested at baseline and 12 weeks later (Jehu, 2012). Therefore, perhaps walking speed is especially susceptible to repeated exposure effects.

The current findings present no significant changes in SRT over time while the mean and variability of CRT progressively improved across the 5 sessions and did not reach a plateau during the standing experiment (Study 1). Interestingly, improvements in SRT were displayed after session 2, but CRT gradually improved and did not reach a plateau after repeated testing during obstacle negotiation (Study 2). These findings emphasize practice-induced gains in cognitive plasticity. They also underline that the repeatability of reaction time (RT) in a dual-task context is dependent not only on the level of difficulty of the RT task, but also the complexity of

the balance task (posture vs obstacle clearance). Previous work has suggested that walking is more attention demanding than standing (Lajoie, Teasdale, Bard, & Fleury, 1996); therefore, this work highlights that a longer exposure to the RT tasks during obstacle negotiation is necessary before reaching a plateau in RT performance. Researchers using RT as an outcome measure following training should be cautious in interpreting the results as attention demand is subject to repeated exposure effects.

Effects of BMT and BMT+C on postural sway, functional mobility, obstacle clearance parameters and attention demand (Research Question 2)

The present experiment revealed no significant improvements in postural sway following BMT or BMT+C (Experiment 4). The literature is mixed in terms of the effectiveness of dual-task interventions to improve posture as a review has reported decreased and no change in postural sway following dual-task training (Wollesen & Voelcker, 2013). Intervention literature has often been criticized for lack of reporting null results. Indeed, a systematic review emphasized that only 19% of balance outcome measures were reported to be significant following progressive resistance training in older adults (Orr, Raymond, & Fiatarone Singh, 2008). It is unclear why some experiments have elicited improvements while others have not; however, some literature proposes that dual-task training is necessary to improve divided attention (Hall, Misko, & Wolf, 2009; Melzer, Marx, & Kurz, 2009). Other experiments have suggested that multifactorial exercise (Shumway-Cook, Gruber, Baldwin, Liao, 1997) as well as exercises targeting sensory systems (Alfieri et al., 2012) should be incorporated in order to elicit benefits to postural control.

Both the BMT and BMT+C groups exhibited clinically significant improvements in the TUG, TUGcog, and TUGman following training (i.e., a decrease in the time to completion of -

0.8 ± 0.5 s; Thiebaud, Funk, & Abe, 2014), while the control group showed no improvements (Experiment 3). Indeed, the improvements in the time to completion extend beyond statistical significance such that they may be interpreted as clinically meaningful. These findings are in line with previous work demonstrating dual-task training-related improvements in functional mobility (Desjardins-Crépeau et al., 2016; Kitazawa et al., 2015; Li et al., 2010). Therefore, both training programs were effective at improving several functional mobility skills, such as turning, sit-to-stand transitions, straight-ahead gait, as well as dual-tasking, all of which are involved during the three TUG measures (Salarian et al., 2009). Interestingly, both training programs resulted in participants surpassing average older adult norms for functional mobility such that they were in the 90th percentile for their age (Bischoff et al., 2003). This suggests that both training groups effectively reached a superior level of functional mobility under dual- and single-task contexts.

This thesis was the first to report the effects of dual-task training on obstacle clearance parameters in older adults (Experiment 5). The results revealed no meaningful improvements in obstacle clearance following BMT or BMT+C. Some research has shown greater clearance over obstacles following single-task training (Lamoureux, Sparrow, Murphy, & Newton, 2003; Lim & Yoon, 2014a) while others suggest that the type of exercise may modulate the selected strategy for obstacle crossing (Zhang, Mao, Riskowski, & Song, 2011). The conflicting findings as to whether training induces improvements in obstacle negotiation may stem from differences in the type of intervention implemented (e.g., aquatic, walking, tai chi, strength training); the outcome measures selected (e.g., obstacle clearance, gait speed, stride length); the length of the intervention (e.g., 12 weeks-8 years of experience), and the precision of the measuring tool (e.g., force platform, motion capture; Lamoureux et al., 2003, Lim & Yoon, 2014a; Zhang et al.,

2011). Importantly, more research is necessary in order to determine the influence of dual-task training on dual-task obstacle clearance parameters.

In general, the BMT and BMT+C groups exhibited significantly faster SRT and CRT during standing as well as during obstacle negotiation following training, while no changes were observed in the control group (Experiments 4 and 5). Recent emerging research has conveyed that dual-task training appears to be necessary in order to improve dual-task performance (Hall et al., 2009; Melzer et al., 2009). Presumably, since both intervention groups trained multi-tasking, their ability to simultaneously perform more than one activity enhanced, suggesting an improved attention demand. Appendix 4 compares the effects of repeated administration of RT during the standing and obstacle clearance protocols at baseline (BMT, BMT+C, Control, and Preliminary Study), and after 12-weeks (BMT, BMT+C, and Control) or after 5 repeated testing sessions (Preliminary Study). According to Appendix 4, the preliminary study led to greater improvements in RT, at times, compared to all of the other groups, perhaps due to increased exposure to the testing protocol. Furthermore, it is possible that improvements over time may have been a function of gaining additional exposure to the specific outcome measures included in the dual-task postural control, dual-task functional mobility, and dual-task obstacle clearance testing protocols, as they were all performed within the same session. Importantly, the control group exhibited no repeated testing effects on RT, likely because they were only tested 3 times in 6 months, while the preliminary study group was tested 5 times within 5 weeks. This indicates that attention demand may be sensitive to repeated administration effects when the testing sessions are close in proximity. Therefore, the improvements in RT exposed in the BMT and BMT+C groups are likely a function of dual-task training, in a larger part, as opposed to repeated testing, as other experiments have also confirmed that dual-task training elicits improvements in

cognition (Law, Barnett, Yau, & Gray, 2014). Future research should take precaution when the intervention is of short duration (e.g., less than 5 weeks), as greater repeated exposure effects may be prevalent.

Effects of the addition of cognitive training on postural sway, functional mobility, obstacle clearance parameters and attention demand (Research Question 3)

It was somewhat surprising that no differences in posture, functional mobility, obstacle clearance parameters or attention demand emerged between the BMT and BMT+C groups (Experiments 3-5) as training cognition has been evidenced to improve cognition and gross motor skills (Li et al., 2010). The attention capacity theory establishes that attention is limited as one can only cope with a certain amount of information at once (Kahneman, 1973). Furthermore, the task prioritization model stipulates that improvements can occur in either or both tasks (Tombu & Jolicoeur, 2005), which may explain the improvements in RT but not postural sway or obstacle clearance parameters. It was particularly unexpected that there were no differences between groups in the TUGcog as the BMT+C group specifically trained the ability to count backwards while performing balance and mobility exercises. Perhaps both training programs provided a favourable attention demanding environment, thus improving the ability simultaneously coordinate multiple tasks to a similar extent. It is also possible that the functional mobility and RT testing were not sensitive enough to detect changes between the two training programs. Altogether, these findings suggest that, whether or not cognitive training is included, training balance and mobility at a high attention demand improves functional mobility and attention demand in older adults.

Effect of a 12-week follow-up on postural sway, functional mobility, obstacle clearance parameters and attention demand (Research Question 4)

Only a few experiments have explored the influence of dual-task training on postural control at a follow-up (Dorfman et al., 2014; Halvarsson et al., 2015). One experiment that showed longer single-leg stance after dual-task training, found that these improvements were not sustained at the 6-month or 1-year follow-up (Halvarsson et al., 2015). Dorfman and colleagues (2014) also found that the significant improvements in the Berg Balance Scale observed after treadmill training with concurrent cognitive training in older adults were not maintained at the 1-month follow-up. The current thesis revealed no improvements in postural sway after BMT or BMT+C, thus the maintenance of improvements in postural sway was not possible (Experiment 4). Perhaps improvements in postural control emerged in previous work due to the increased difficulty of the tasks (i.e., 1-legged stance and Berg Balance Scale; Dorfman et al., 2014; Halvarsson et al., 2015) relative to the feet apart and feet in semi-tandem stances included in the current thesis. Notably, the cumulative findings underline the importance of sustained involvement in dual-task training to provoke and maintain benefits in postural control.

Limited research has examined the effects of dual-task training on functional mobility at a follow-up. Two experiments have incorporated a component of dual-tasking in the intervention and showed sustained improvements in functional mobility at the follow-up (Carvalho, Marques, & Mota, 2009; Lacroix et al., 2015). Other work that has implemented single-task interventions and indicated that functional mobility remained above baseline values (Kalapotharakos, Diamantopoulos, & Tokmakidis, 2010) or declined to baseline values (Coetsee, Terblanche, 2015). The results from the present thesis support the notion that improvements in functional mobility are preserved at a 12-week follow-up after dual-task training (Experiment 3). It is

possible that functional mobility would decline to baseline values with longer follow-up durations. Future research should determine the extent of the sustained improvements in functional mobility over time.

No known experiments have investigated the influence of dual-task training on obstacle clearance in older adults. Only one experiment has examined the influence of a follow-up on obstacle clearance parameters following a single-task aquatic exercise intervention in older adults (Lim & Yoon, 2014b). Unlike the present results, this experiment evoked significantly greater toe and heel clearance following aquatic training and sustained improvements at the 8-week follow-up in most conditions (Lim & Yoon, 2014b). The current thesis revealed no changes in obstacle clearance parameters following BMT or BMT+C and no changes at the follow-up (Experiment 5). The discrepancy in these findings may stem from differences in the frequency, intensity, type and length of interventions conducted. Again, since obstacle clearance values from this thesis were within safe crossing ranges (Weerdesteyn et al., 2006), perhaps more attention was available instead for the RT tasks, thereby facilitating improvements in attention demand to occur following training and sustained improvements over time. More research is necessary in order to ascertain whether dual-task training improves obstacle clearance parameters and whether these improvements can be maintained over time.

In line with the scarcity of research, preserved improvements in cognition have been observed following cognitive-dual-task training in older adults (Eggenberger et al., 2015; Oswald et al., 2006) as well as cognitive training alone (Valenzuela & Sachdev, 2009; Marusic et al., 2016). In fact, significant improvements were observed in cognition following 2 weeks of cognitive training during bedrest in older adults, and sustained improvements after a 400-day follow-up (Marusic et al., 2016). These findings emphasize the integrity of cognitive training as

despite the negative effects of bedrest, participants still improved and sustained cognitive training effects. Furthermore, Oswald et al. (2006) found that cognition was sustained in the cognitive and physical training group, whereas no maintenance in cognition was shown for the group that solely completed physical exercises. Interestingly, the BMT group also sustained improvements in RT, although they did not complete cognitive training (Experiments 4 and 5). It is possible that because both the BMT and BMT+C group trained at a high level of attention demand, improvements in RT were preserved at the follow-up. In sum, these findings are important as aging has been related to declines in cognitive functioning (Deary et al., 2009). These results highlight that BMT and BMT+C equally contribute to the maintenance of long-term cognitive performance.

Significant contributions

The results from this dissertation significantly contribute to the field of Human Kinetics. Firstly, a novel dual-task obstacle clearance protocol was developed (Study 2 and Experiment 5). Typically, previous research has explored the influence of crossing 1 or 2 obstacles (e.g., Chen et al., 1991; Chou et al., 1998; Lowrey, Watson, Vallis, 2007; Rhea & Rietdyk, 2011; Worden, De Jong, & Vallis, 2016); however, the current thesis included a series of obstacles of varying heights to cross in order to simulate negotiating uneven terrain. Future studies could implement this protocol in order to further investigate accommodation strategies during obstacle clearance in older adults as well as in other populations.

Secondly, no previous research has explored the influence of repeated exposure to a dual-task postural sway protocol, a dual-task functional mobility protocol, or a dual-task obstacle clearance protocol in older adults (Studies 1-3). Results from this thesis propose that older adults are susceptible to learning effects due to serial administration of the testing protocols. These

findings are critical for intervention research. Researchers should take precaution when interpreting their results as improvements post-intervention may, in part, be due to repeated exposure to the testing protocol, especially if the testing sessions are in close proximity. The findings from Studies 1-3 may serve as a basis to interpret whether clinically relevant changes have emerged following a dual-task intervention when implementing dual-task postural sway, dual-task functional mobility, or dual-task obstacle clearance protocols in older adults.

Thirdly, the results from this thesis also provide valuable information for the field of Human Kinetics as two novel dual-task interventions were designed and implemented in older adults (Experiments 3-5). The majority of dual-task interventions have assimilated cognitive dual-tasks into exercise regimes (Desjardins-Crépeau et al., 2016; Falbo, Condello, Capranica, Forte & Pesce, 2016; van het Reve & de Bruin, 2014); however limited research has investigated the impact of motor dual-tasks paired with balance training (Pichierri, Coppe, Lorenzetti, Murer, & de Bruin, 2012; Schättin, Arner, Gennaro, & de Bruin, 2016). In addition, no previous research has designed an intervention to include the simultaneous performance of motor and cognitive tasks during balance training. Therefore, the BMT and BMT+C shed new light on these gaps in the literature. Both interventions were successful at improving functional mobility and attention demand in older adults. Interestingly, BMT+C did not elicit further benefits to the outcome measures. A systematic review recommends that balance training interventions should incorporate cognitive dual-tasks for older adults, since falls often occur during situations that are attention demanding (Pichierri, Wolf, Murer, & de Bruin, 2011). Cognitive decline has also been associated with increased fall-risk (Beauchet et al., 2005). This thesis contributes to the existing literature that incorporating cognitive training in a balance training regime may not be necessary. That is, as long as the training maintains a high attentional load (i.e., concurrently performing

motor and/or cognitive tasks during balance activities), benefits to dual-tasking are inclined to occur. This finding is thus important for the design of a future single-blinded randomized controlled dual-task trial. It also provides new insight into the prescription of exercise, having been demonstrated that 12 weeks of individualized and progressive multi-task balance training is an effective training method for the older population.

Fourthly, some single-task training literature has posited that interventions targeting precise variables produce significant improvements (Hu & Woollacott, 1994; Wolf et al., 1997), whereas those that are more general do not (Jehu, 2012). For example, Hu and Woollacott (1994) tested and trained participants for 10 days on the same outcome measures, and found significant improvements after the intervention relative to the general training group. To date, little is known about the extent and limits of transfer effects after dual-task training. This thesis offers greater understanding of transfer effects as the BMT and BMT+C programs were significantly different from the testing protocol; nevertheless, both groups exhibited marked improvements in functional mobility and attention demand (Experiments 3-5). This provides evidence that dual-task training programs promote the transfer of skills to novel, yet similar tasks in older adults. Perhaps postural sway and obstacle clearance were far transfer tasks, and therefore, participants did not exhibit subsequent improvements. Further research is necessary in order to comprehensively elucidate the extent and limits of transfer effects in the older population.

Fifthly, there is a lack of research that has included a follow-up after dual-task interventions in older adults (e.g., Eggenberger et al., 2015; Oswald et al., 2006; Silsupadol et al., 2009; Silsupadol et al., 2006). Understanding the persistence of training-related improvements is critical in order to determine whether the training had long-term impacts on dual-task ability. Notably, the current thesis provides this important information, in that BMT and BMT+C

provoked improvements in functional mobility and attention demand, with lasting benefits 12 weeks after training (Experiments 3-5). Future research should consider further investigating which dual-task practice conditions offer optimal retention, as well as exploring ongoing maintenance programs (Agmon, Belza, Nguyen, Logsdon, & Kelly, 2014).

Sixthly, this dissertation also supports various theoretical frameworks in the field of Motor Control. The findings from this thesis support the attention capacity theory. This theory stipulates that practice-related improvements in performance may manifest on either or both tasks during dual-tasking (Kahneman, 1973; Rемаud, Boyas, Lajoie, & Bilodeau, 2013). During both the dual-task postural sway protocol (Experiment 4) and dual-task obstacle clearance protocol (Experiment 5), participants in the BMT and BMT+C groups improved attention demand, but not postural sway or obstacle clearance parameters. It has been suggested that older adults unconsciously adopt a “posture first” strategy during attention demanding dual-task balance tasks (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). That is, they naturally attend more to balance than to the secondary task, presumably in order to remain upright (Yogev-Seligmann et al., 2010). A reduced ability to effectively allocate attention can be detrimental to balance, and increase the risk of falls (Siu, Chou, Mayr, van Donkelaar, & Woollacott, 2009). The findings from this thesis point towards the BMT and BMT+C groups adopting the “posture first” strategy as balance was likely prioritized during all testing sessions as no changes were observed in posture or obstacle clearance parameters. Additionally, participants in the preliminary study likely prioritized posture first; as no improvements were observed across sessions in postural sway (Study 1), and minimal improvements were observed in obstacle clearance parameters (Study 2), while significant improvements in attention demand were displayed. Because of dual-task training (Experiments 4 and 5) or repeated exposure to the

testing protocol (Studies 1 and 2), the ability to perform two tasks simultaneously improved, thereby allowing more attention to be available for the RT task, thus resulting in subsequent improvements.

Lastly, this thesis may also support the bottleneck theory. The bottleneck theory deduces that parallel processing may become challenging when similar cognitive processing operations are employed (Pashler, 1994). In consequence, a bottleneck effect occurs and the tasks must be completed sequentially (Pashler, 1994). The central nervous system is thought to temporarily delay the performance of the non-prioritized task, corresponding to associated performance decrements (Fraizer & Mitra, 2008). The slower information processing of the RT tasks at baseline in the current thesis denotes that a bottleneck effect in central processing may have emerged. It is possible that with prolonged training (Experiments 4 and 5), or increased exposure to the testing protocol (Studies 1 and 2), participants may have effectively reallocated more attention to the RT tasks with practice, thereby facilitating faster RTs. It is therefore possible that participants improved dual-task automaticity. Tasks should be viewed on a continuum of varying degrees of automaticity, instead of viewing some tasks as automatic, and therefore not requiring attention (Shumway-Cook & Woollacott, 2007). All tasks require a certain level of attention, but the amount will change as a function of the degree of automaticity. It has also been suggested that automatic tasks possess an increase in the speed of mental operations (Cohen, Dunbar, & McClelland, 1990). This is because automatic tasks are less vulnerable to distractions in perceptual processes and interference of a competing task, as they are highly practiced processes (Cohen et al., 1990). In sum, the improved attention demand after dual-task training, and after repeated exposure to the testing protocol, suggests that participants effectively decreased dual-task interference, facilitated greater automaticity, and reduced the bottleneck effect.

Limitations

Sample population

The findings from this thesis may not be generalizable to all older adults. The sample homogeneity restricts generalization to relatively healthy community-dwelling older adults, independent walkers, and highly motivated individuals. The BMT and BMT+C groups volunteered to exercise 3 times per week; however, approximately 28% of older adults aged 65-74 are inactive in the United States (Watson et al., 2016), implying that these findings may not be applicable for sedentary older adults.

Testing protocol

Because the sample population was healthy, certain tests, such as the postural tasks, may have been too simple and may not have allowed for improvements to occur. One of the advantages to this thesis was the implementation of a wide range of tasks in the testing protocol. By testing multiple outcome measures across various stance and walking tests, a broader assessment of overall balance was accomplished.

The experimenter was not subjected to a double-blind procedure as the experimenter also trained approximately half of the participants and tested each participant across all testing sessions. Thus, conscious or subconscious observer bias may have affected the results. Likewise, participants were not blind to the intervention or the control period. However, due to the nature of training programs, it is impossible to support a double-blind procedure. Future research can use the findings from this dissertation to design a single-blinded randomized controlled trial according to the Consolidated Standards of Reporting Trials (CONSORT).

Because one large preliminary study examined the repeated administration of a dual-task postural control testing protocol (Study 1), followed by a functional mobility testing protocol

(Study 3), followed by a dual-task obstacle clearance protocol (Study 2) in older adults once per week for 5 weeks, it is possible that improvements in outcome measures reported across studies may have been a function of completing the entire testing protocol as opposed to solely the individual aspects. Equally, a separate experiment examined the effects of balance and mobility training (BMT) and balance and mobility plus cognitive training (BMT+C) on dual-task postural control (Experiment 4), dual-task functional mobility (Experiment 3), and dual-task obstacle clearance (Experiment 5) in a different cohort of older adults as the preliminary study. It is possible that participants may have received additional practice from completing the various aspects of the overall testing protocol, which may have had an influence on performance.

Training programs

Inconsistent delivery of the instructions for the balance exercises may have occurred and led to inter- and intra-trainer variability. There were 3 trainers in total (2 research assistants aided the experimenter). The trainers may have also provided inconsistent amounts of encouragement within and between participants during the interventions, which could have altered the results. Additionally, while the training program was standardized for those in the intervention groups, some variation in the exercises existed, as participants progressed at their own pace. This can be seen as a benefit considering that the program was individualized for each participant depending on their capabilities.

It is possible that deterioration in different combinations of the systems involved in balance control could have occurred across participants (Horak, 2006). To this end, some individuals may have benefited from certain aspects of the training program, while other participants may have experienced little to no changes in balance. Individual differences in the progression of improvement during the training program may have contributed to inherent

variability and a lack of apparent improvements in postural sway and obstacle clearance. More specifically, some participants may have demonstrated marked improvements in the dynamic exercises, but not as many improvements in the static exercises. These improvements may not have been captured in the balance testing in the BMT and BMT+C groups if a system that was improved was not examined. For example, simultaneously performing 3 tasks was trained on the balance obstacle course in the BMT+C group; however triple-tasking was not part of the testing battery. Therefore, it is possible that the BMT+C group improved in the systems that were not tested.

Conclusion

In conclusion, BMT and BMT+C equally contributed to not only improved functional mobility (Experiment 3) and attention demand (Experiments 4 and 5), but sustained improvement over time in older adults (Experiments 3-5). No differences in postural sway (Experiment 4) or obstacle clearance parameters (Experiment 5) emerged following BMT or BMT+C. Although repeated exposure to the testing protocol delineated faster RT (Studies 1 and 2) and walking speed (Study 2) in the preliminary studies, the improvements exposed in functional mobility (Experiment 3) and attention demand (Experiments 4 and 5) following BMT and BMT+C are likely not a function of repeated exposure as no changes emerged in the control group over time (Experiments 3-5). Perhaps improvements from repeated testing protocols only materialize when the testing is performed close in proximity (i.e., once per week for 5 weeks; Studies 1-3). The additional cognitive training that the BMT+C group received did not elicit further benefits across any of the outcome measures compared to the BMT group (Experiments 3-5). Globally, these findings assert that, whether or not cognitive training is included, attention

demanding dual-task training improves functional mobility and attention demand, and sustains these improvements over time in older adults.

References

- Agmon, M., Kelly, V.E., Logsdon, R.G., Nguyen, H., Belza, B. (2015). The effects of EnhanceFitness (EF) training on dual-task walking in older adults. *J Appl Gerontol*, 34, 128-142.
- Alfieri, F.M., Riberto, M., Gatz, L.S., Ribeiro, C.P., Lopes, J.A., & Battistella, L.R. (2012). Comparison of multisensory and strength training for postural control in the elderly. *Clin Interv Aging*, 7, 119–125.
- Beauchet, O., Dubost, V., Herrmann, F., Rabilloud, M., Gonthier, R., & Kressig, R.W. (2005). Relationship between dual-task related gait changes and intrinsic risk factors for falls among transitional frail older adults. *Aging Clin Exp Res*, 17(4), 270-275.
- Bischoff, H., Stähelin, H., Monsch, A., Iversen, M.D., Weyh, A., von Dechend, M., Akos, R., Conzelmann, M., Dick, W., & Theiler, R. (2003). Identifying a cut-off point for normal mobility: a comparison of the timed ‘up and go’ test in community-dwelling and institutionalised elderly women. *Age Ageing*, 32, 315-320.
- Carvalho, M.J., Marques, E., & Mota, J. (2009). Training and detraining effects on functional fitness after a multicomponent training in older women. *Gerontology*, 55, 41-48.
- Chen, H.C., Schultz, A.B., Ashton-Miller, J.A., Giordani, B., Alexander, N.B., & Guire, K.E. (1996). Stepping over obstacles: Dividing attention impairs performance of old more than young adults. *J Gerontol A Biol Sci Med Sci*, 51, 116–122.
- Chou, L., & Draganich, L.F. (1998). Placing the trailing foot closer to an obstacle reduces flexion of the hip, knee, and ankle to increase the risk of tripping. *Journal of Biomechanics*, 31, 685–691.

- Coetsee, C., & Terblanche, E. (2015). The time course of changes induced by resistance training and detraining on muscular and physical function in older adults. *Eur Rev Aging Phys Act*, 29, 12, 7.
- Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the stroop effect. *Psychol Rev*, 97(3), 332-361.
- Deary, I.J., Corley, J., Gow, A.J., Harris, S.E., Houlihan, L.M., Marioni RE, Penke, L., Rafnsson, S.B., & Starr, J.M. (2009). Age-associated cognitive decline. *British Medical Bulletin*, 92, 135–152.
- Desjardins-Crépeau, L., Berryman, N., Fraser, SA., Vu, TT., Kergoat, MJ., Li, KZ., Bosquet, L., & Bherer, L. (2016). Effects of combined physical and cognitive training on fitness and neuropsychological outcomes in healthy older adults. *Clin Interv Aging*, 19(11), 1287-1299.
- Diamantopoulos, I.I., Clifford, E., & Birchall, J.P. (2003). Short-term learning effects of practice during the performance of the tandem romberg test. *Clin Otolaryngol*, 28, 308-313.
- Dorfman, M., Herman, T., Brozgol, M., Shema, S., Weiss, A., Hausdorff, JM., & Mirelman, A. (2014). Dual-task training on a treadmill to improve gait and cognitive function in elderly idiopathic fallers. *J Neurol Phys Ther*, 38(4), 246-253.
- Eggenberger, P., Schumacher, V., Angst, M., Theill, N., & de Bruin, E.D. (2015). Does multicomponent physical exercise with simultaneous cognitive training boost cognitive performance in older adults? A 6-month randomized controlled trial with a 1-year follow-up. *Clin Interv Aging*, 17(10), 1335-1349.

- Elliott, C., Murray, A. (1998). Repeatability of body sway measurements; day-to-day variation measured by sway magnetometry. *Physiol Meas*, 19, 159-164.
- Falbo, S., Condello, G., Capranica, L., Forte, R., & Pesce, C. (2016). Effects of physical-cognitive dual task training on executive function and gait performance in older adults: A randomized controlled trial. *Biomed Res Int*, Dec 8. Epub ahead of print.
- Fraizer, E.V., & Mitra, S. (2008). Methodological and interpretive issues in posture-cognition dual-tasking in upright stance. *Gait Posture*, 27, 271-279.
- Geurts, A.C.H., Nienhuis, B., & Mulder, T.W. (1993). Intrasubject variability of selected force platform parameters in the quantification of postural control. *Arch Phys Med Rehabil*, 74, 1144-1450.
- Hall, C.D., Miszko, T., & Wolf, S.L. (2009). Effects of Tai Chi intervention on dual task ability in older adults: A pilot study. *Arch Phys Med Rehabil*, 90(3), 525–529.
- Halvarsson, A., Oddsson, L., Franzén, E., & Ståhle, A. (2016). Long-term effects of a progressive and specific balance-training programme with multi-task exercises for older adults with osteoporosis: A randomized controlled study. *Clin Rehabil*, 30(11), 1049-1059.
- Horak, F. B. (2006). Postural orientation and equilibrium: What we need to know about neural control of balance to prevent falls? *Age Ageing*, 35, ii7-ii11.
- Hu, M., & Woollacott, M. H. (1994). Multisensory training of standing balance in older adults: Postural stability and one-leg stance balance. *J Gerontol*, 49, 52-61.
- Jehu, D. (2012). The effects of a multifactorial exercise and balance training program on balance control in older adults. Brock University, St. Catharines, Ontario, Canada.
- Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs: New Jersey.

- Kalapothisarakos, V.I., Diamantopoulos, K., & Tokmakidis, S.P. (2010). Effects of resistance training and detraining on muscle strength and functional performance of older adults aged 80 to 88 years. *Aging Clin Exp Res*, 22, 134-140.
- Kitazawa, K., Showa, S., Hiraoka, A., Fushiki, Y., Sakauchi, H., & Mori, M. (2015). Effect of a dual-task net-step exercise on cognitive and gait function in older adults. *J Geriatr Phys Ther*, 38, 133-140.
- Lacroix, A., Kressig, R.W., Muehlbauer, T., Gschwind, Y.J., Pfenninger, B., Bruegger, O., Granacher, U. (2016). Effects of a supervised versus an unsupervised combined balance and strength training program on balance and muscle power in healthy older adults: A randomized controlled trial. *Gerontology*, 62(3), 275-288
- Lajoie, Y., Teasdale, N., Bard, C., & Fleury, M. (1996). Upright standing and gait: are there changes in attentional requirements related to normal aging? *Exp Aging Res*, 22(2), 185-198.
- Lamoureux, E., Sparrow, W.A., Murphy, A., Newton, R.U. (2003). The effects of improved strength on obstacle negotiation in community-living older adults. *Gait Posture*, 17, 273-283.
- Law, L.L., Barnett, F., Yau, M.K., & Gray, M.A. (2014). Effects of combined cognitive and exercise interventions on cognition in older adults with and without cognitive impairment: A systematic review. *Ageing Res Rev*, 15, 61–75.
- Li, K.Z., Roudaia, E., Lussier, M., Bherer, L., Leroux, A., & McKinley, P.A. (2010). Benefits of cognitive dual-task training on balance performance in healthy older adults. *J Gerontol A Biol Sci Med Sci*, 65, 1344-1352.

- Lim, H.S., & Yoon, S. (2014a). The influence of short-term aquatic training on obstacle crossing in gait by the elderly. *J Phys Ther Sci*, 26, 1219–1222.
- Lim, H.S., & Yoon, S. (2014b). The training and detraining effects of 8 weeks of water exercise on obstacle avoidance in gait by the elderly. *J Phys Ther Sci*, 26, 1215–1218.
- Lowrey, C., Watson, A., & Vallis, L. (2007). Age-related changes in avoidance strategies when negotiating single and multiple obstacles. *Exp Brain Res*, 182, 289–299.
- Marusic, U., Giordani, B., Moffat, S.D., Petrič, M., Dolenc, P., Pišot, R., Kavcic, V. (2016). Computerized cognitive training during physical inactivity improves executive functioning in older adults. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn*, 12, 1-21.
- Melzer, I., Marx, R., & Kurz, I. (2009). Regular exercise in the elderly is effective to preserve the speed of voluntary stepping under single-task condition but not under dual-task condition. *Gerontology*, 55(1), 49–57.
- Nordahl, S.H., Aasen, T., Dyrkorn, B.M., Eidsvik, S., & Molvaer, O.I. (2000). Static stabilometry and repeated testing in a normal population. *Aviat Space Environ Med*, 71, 889-893.
- Orr, R., Raymond, J., & Fiatarone Singh, M. (2008). Efficacy of progressive resistance training on balance performance in older adults: A systematic review of randomized controlled trials. *Sports Med*, 38(4), 317-343.
- Oswald, W.D., Gunzelmann, T., Rupprecht, R., & Hagen, B. (2006). Differential effects of single versus combined cognitive and physical training with older adults: the SimA study in a 5-year perspective. *Eur J Ageing*, 3, 179–192.

- Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychol Bull*, 116, 220-244.
- Pichierri, G., Coppe, A., Lorenzetti, S., Murer, K., & de Bruin, ED. (2012). The effect of a cognitive-motor intervention on voluntary step execution under single and dual task conditions in older adults: A randomized controlled pilot study. *Clin Interv Aging*, 7, 175-184.
- Pichierri, G., Wolf, P., Murer, K., & de Bruin, E. (2011). Cognitive and cognitive-motor interventions affecting physical functioning: A systematic review. *BMC Geriatr*, 11, 29.
- Remaud, A., Boyas, S., Lajoie, Y., & Bilodeau, M. (2013). Attentional focus influences postural control and reaction time performances only during challenging dual-task conditions in healthy young adults. *Exp Brain Res*, 231(2), 219-229.
- Rhea, C., & Rietdyk, S. (2011). Influence of an unexpected perturbation on adaptive gait behavior. *Gait Posture*, 34, 439–441
- Salarian, A., Zampieri, C., Horak, F.B., Carlson-Kuhta, P., Nutt, J.G., & Aminian, K. (2009). Analyzing 180 degrees turns using an inertial system reveals early signs of progression of parkinson's disease. *Conf Proc IEEE Eng Med Biol Soc*, 1, 224–227.
- Schättin, A., Arner, R., Gennaro, F., & de Bruin, ED. (2016). Adaptations of prefrontal brain activity, executive functions, and gait in healthy elderly following exergame and balance training: A randomized-controlled study. *Front Aging Neurosci*, 23(8), 278.
- Shumway-Cook, A., & Woollacott, M.H. (2007). *Motor control: Translating research into clinical practice*, third edition. Lippincott Williams & Wilkins.

- Shumway-Cook, A., Woollacott, M., Kerns, K. A., & Baldwin, M. (1997). The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *J Gerontol A Biol Sci Med Sci*, 52(4), M232-240.
- Shumway-Cook, A., Gruber, W., Baldwin, M., & Liao, S. (1997). The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. *Phys Ther*, 77(1), 46-57.
- Silsupadol, P., Shumway-Cook, A., Lugade V, van Donkelaar, P., Chou, LS., Mayr, U., & Woollacott, MH. (2009). Effects of single-task versus dual-task training on balance performance in older adults: A double-blind, randomized controlled trial. *Arch Phys Med Rehabil*, 90(3), 381–387.
- Silsupadol, P., Siu, KC., Shumway-Cook, A., & Woollacott, MH. (2006). Training of balance under single- and dual-task conditions in older adults with balance impairment. *Phys Ther*, 86(2), 269–281.
- Siu, K.C., Chou, L.S., Mayr, U., van Donkelaar, P., & Woollacott, M.H. (2009). Attentional mechanisms contributing to balance constraints during gait: The effects of balance impairments. *Brain Res*, 1248, 59-67.
- Tombu, M., & Jolicoeur, P. (2005). Testing the predictions of the central capacity sharing model. *J Exp Psychol Hum Percept Perform*, 31,790–802.
- Valenzuela, M., & Sachdev, P. (2009). Can cognitive exercise prevent the onset of dementia? Systematic review of randomized clinical trials with longitudinal follow-up. *Am J Geriatr Psychiatry*, 17(3), 179–187.

- van het Reve, E., & de Bruin, ED. (2014). Strength-balance supplemented with computerized cognitive training to improve dual task gait and divided attention in older adults: A multicenter randomized-controlled trial. *BMC Geriatr*, Dec 15; 14, 134.
- Watson, K.B., Carlson, S.A., Gunn, J.P., Galuska, D.A., O'Connor, A., Greenlund, K.J., & Fulton, J.E. (2016). Physical inactivity among adults aged 50 years and older - United States, 2014. *MMWR Morb Mortal Wkly Rep*,65(36), 954-958.
- Weerdesteyn, V., Rijken, H., Geurts, A.C., Smits-Engelsman, B.C., Mulder, T., & Duysens, J. (2006). A five-week exercise program can reduce falls and improve obstacle avoidance in the elderly. *Gerontol*, 52, 131-141.
- Wolf, SL., Barnhart, HX., Ellison, GL., & Coogler, CE. (1997). The effect of tai chi quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. *Frailty and Injuries: Cooperative studies on intervention techniques. Phys Ther*, 77(4), 371-381.
- Wollesen, B., & Voelcker-Rehage, C. (2013). Training effects on motor–cognitive dual-task performance in older adults. *Eur Rev Aging Phys Act*, 11(1), 5-24.
- Worden, T., De Jong, A., & Vallis, L. (2016). Do characteristics of a stationary obstacle lead to adjustments in obstacle stepping strategies? *Gait Posture*, 43, 38-41.
- Wulf, G., Weigelt, M., Poulter, D., & McNevin, N. (2003). Attentional focus on suprapostural tasks affects balance learning. *Q J Exp Psychol A*, 56(7), 1191-1211.
- Yogev, G., Giladi, N., Peretz, C., Springer, S., Simon, E. S., & Hausdorff, J. M. (2005). Dual tasking, gait rhythmicity, and Parkinson's disease: Which aspects of gait are attention demanding? *Eur J Neurosci*, 22(5), 1248-1256.

Zhang, C., Mao, D., Riskowski, J.L., & Song, Q. (2011). Strategies of stepping over obstacles: The effects of long-term exercise in older adults. *Gait Posture*, 34, 191–196

APPENDIX 1: COMPLETE LIST OF OBSTACLE COURSE TASKS AND LEVELS OF PROGRESSION

Stipulations for Advancing Levels on the Obstacle Course

1. No errors on tasks
2. No gaps in time during story telling/categories
3. You cannot advance in a level during one session (increases repetition)
4. You must perform the task successfully once before advancing

Obstacle Course Tasks

1. Stepping
2. Reaching
3. Balance Disk
4. BOSU Ball
5. Elastic Bands
6. Walking
7. Square Foam
8. Square Wobble Board
9. Circular Wobble Board
10. Stepper
11. Half-Foam Rollers
12. Balance Pods
13. Seated Balance

1. Stepping

Level 1

- Skip Rope-step over with both feet along a flat skip rope in ML (medial-lateral)

Level 2

- Skip Rope-step over with both feet along a flat skip rope in AP (anterior-posterior)

Level 3

- Half-Foam Rollers-step over with both feet in ML

Level 4

- Half-Foam Rollers-step over with both feet in AP

Level 5

- Stepper-step over one riser and back in ML

Level 6

- Stepper-step over one riser and back in AP

Level 7

- Skip Rope-hop over with both feet along a flat skip rope in ML

Level 8

- Skip Rope-hop over with both feet along a flat skip rope in AP

Level 9

- Half Foam Rollers-hop over with both feet in ML

Level 10

- Half Foam Rollers-hop over with both feet in AP

Level 11

- Skip Rope-hop over with one foot along a flat skip rope (alternate feet) in ML

Level 12

- Skip Rope-hop over with one foot along a flat skip rope (alternate feet) in AP

Level 13

- Half-Foam Rollers-hop over with one foot (alternate feet) in ML

Level 14

- Half-Foam Rollers-hop over with one foot (alternate feet) in AP

Level 15

- Stepper-hop over one riser and back in ML

Level 16

- Stepper-hop over one riser and back in AP

2. Reaching

Level 1

- Reaching-laterally high and low, while standing on a foam surface with feet together (FT)

Level 2

- Reaching-forwards with both hands, while standing on a foam surface with FT

Level 3

- Reaching-high and low in opposite directions, while standing on a foam surface with FT

Level 4

- Reaching-laterally high and low, while standing on a balance disk surface with FT

Level 5

- Reaching-forwards with both hands, while standing on a balance disk surface with FT

Level 6

- Reaching-high and low in opposite directions, while standing on a balance disk surface with FT

Level 7

- Reaching-laterally high and low, while standing on a both sides up (bosu) ball surface with FT

Level 8

- Reaching-forwards with both hands, while standing on a bosu ball surface with FT

Level 9

- Reaching-high and low in opposite directions, while standing on a bosu ball surface with FT

Level 10

- Reaching-laterally high and low, while standing on a square wobble board in ML with FT

Level 11

- Reaching-forwards with both hands, while standing on a square wobble board in ML with FT

Level 12

- Reaching-high and low in opposite directions, while standing on a square wobble board in ML with FT

Level 13

- Reaching-laterally high and low, while standing on a square wobble board in AP with FT

Level 14

- Reaching-forwards with both hands, while standing on a square wobble board in AP with FT

Level 15

- Reaching-high and low in opposite directions, while standing on a square wobble board in AP with FT

Level 16

- Reaching-laterally high and low, while standing on a square wobble board in diagonal with FT

Level 17

- Reaching-forwards with both hands, while standing on a square wobble board in diagonal with FT

Level 18

- Reaching-high and low in opposite directions, while standing on a square wobble board in AP with FT

Level 19

- Reaching-laterally high and low, while standing on a circular wobble board with FT

Level 20

- Reaching-forwards with both hands, while standing on a circular wobble board with FT

Level 21

- Reaching-high and low in opposite directions, while standing on a circular wobble board with FT

3. Balance Disk

Level 1

- Balance Disk-stand with feet apart (Use two balance disks)

Level 2

- Balance Disk-stand with feet together (Use one balance disk)

Level 3

- Balance Disk-stand in semi-tandem (alternate leading limb; use one balance disk)

Level 4

- Balance Disk-stand in tandem (alternate leading limb; use two balance disks)

Level 5

- Balance Disk-stand on one foot (alternate limb; use one balance disk)

4. Bosu Ball

Level 1

- Bosu Ball-step and turn 360 degrees

Level 2

- Bosu Ball-stepping onto and off of bosu ball (all directions, alternating leading leg)

Level 3

- Bosu Ball-step and turn 360 degrees while receiving perturbations

Level 4

- Bosu Ball-touch foot down in the front, side and back

Level 5

- Bosu Ball-touch foot down in the front, side and back while receiving perturbations

Level 6

- Bosu Ball-tree pose (alternate feet)

Level 7

- Bosu Ball-tree pose while receiving perturbations (alternate feet)

Level 8

- Bosu Ball-stork position (alternate feet)

Level 9

- Bosu Ball-stork position while receiving perturbations (alternate feet)

5. Elastic Bands

Level 1

- Elastics-stand on a firm surface with feet together (FT) while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 2

- Elastics-stand on a firm surface with FT while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 3

- Elastics-stand on a foam surface with FA while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 4

- Elastics-stand on a foam surface with FA while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 5

- Elastics-stand on a foam surface with FT while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 6

- Elastics-stand on a foam surface with FT while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 7

- Elastics-stand on a balance disk with FA while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 8

- Elastics-stand on a balance disk with FA while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 9

- Elastics-stand on a balance disk with FT while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 10

- Elastics-stand on a balance disk with FT while pulling on elastic bands to the right, left, above the head and to the toes

Level 11

- Elastics-stand on a bosu ball with FA while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 12

- Elastics-stand on a bosu ball with FA while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 13

- Elastics-stand on a bosu ball disk with FT while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 14

- Elastics-stand on a bosu ball disk with FT while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 15

- Elastics-stand on a firm surface in tandem stance while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 16

- Elastics-stand on a firm surface in tandem stance while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 17

- Elastics-stand on a foam surface in tandem stance while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 18

- Elastics-stand on a foam surface in tandem stance while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 19

- Elastics-stand on a balance disk in tandem stance while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 20

- Elastics-stand on a balance disk in tandem stance while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

Level 21

- Elastics-stand on a bosu ball in tandem stance while pulling on elastic bands to the right, left, above the head and to the toes while facing towards and away from the elastics

Level 22

- Elastics-stand on a bosu ball in tandem stance while pulling on elastic bands to the right, left, above the head and to the toes with the elastics to the sides (perform on both sides)

*Note-use elastics with appropriate resistance levels depending on the participants' strength

6. Walking

Level 1

- Walking-walk in tandem along a taped path

Level 2

- Walking-walk along a taped path while rolling a heavy medicine ball on alternate feet

Level 3

- Walking-walk along a taped path while rolling a medium medicine ball on alternate feet

Level 4

- Walking-walk along a taped path while rolling a tennis ball on alternate feet

Level 5

- Walking-walk along a taped path while rolling a heavy medicine ball on one foot

Level 6

- Walking-walk along a taped path while rolling a medium medicine ball on one foot

Level 7

- Walking-walk along a taped path while rolling a tennis ball on one foot

Level 8

- Walking-walk along a taped path while doing the grape-vine

Level 9

- Walking-walk along a taped path while doing the grape-vine while rolling a heavy medicine ball on one foot

Level 10

- Walking-walk along a taped path while doing the grape-vine rolling a medium medicine ball on one foot

Level 11

- Walking-walk along a taped path while doing the grape-vine rolling a tennis ball on one foot

Level 12

- Walking-walk and the trainer instructs to randomly change direction (forward/back) while rolling a heavy medicine ball on alternate feet and do the grapevine (left/right)

Level 13

- Walking-walk and the trainer instructs to randomly change direction (forward/back) while rolling a medium medicine ball on alternate feet and do the grapevine (left/right)

Level 14

- Walking-walk and the trainer instructs to randomly change direction (forward/back) while rolling a tennis ball on alternate feet and do the grapevine (left/right)

Level 15

- Walking-walk and the trainer instructs to randomly change direction (forward/back) while rolling a heavy medicine ball on the same foot and do the grapevine (left/right)

Level 16

- Walking-walk and the trainer instructs to randomly change direction (forward/back) while rolling a medium medicine ball on same foot and do the grapevine (left/right)

Level 17

- Walking-walk and the trainer instructs to randomly change direction (forward/back) while rolling a tennis ball on the same foot and do the grapevine (left/right)

Level 18

- Hopping-walk and the trainer instructs to randomly change direction (forward/back) while rolling a heavy medicine ball on the same foot and do the grapevine (left/right; keep the foot on the ball at all times)

Level 19

- Hopping-walk and the trainer instructs to randomly change direction (forward/back) while rolling a medium medicine ball on the same foot and do the grapevine (left/right; keep the foot on the ball at all times)

Level 20

- Hopping-walk and the trainer instructs to randomly change direction (forward/back) while rolling a tennis ball on the same foot and do the grapevine (left/right; keep the foot on the ball at all times)

7. Square Foam

Level 1

- Square Foam-stand with feet apart

Level 2

- Square Foam-stand with feet together (FT)

Level 3

- Square Foam-stand with FT and shift weight in the anterior-posterior and medial-lateral directions

Level 4

- Square Foam-march in place

Level 5

- Square Foam-stand with feet in tandem (alternate right and left foot forward)

Level 6

- Square Foam-stand on one foot (alternate right and left foot forward)

Level 7

- Square Foam-hop with FT

Level 7

- Square Foam-hop from one tandem position to the other and hold for 5 seconds

Level 8

- Square Foam-hopping on one foot (alternate feet)

8. Square Wobble Board

Level 1

- Square Wobble board in ML and balance disk-stand with one foot on each object and keep them horizontal

Level 2

- Square Wobble board in AP and balance disk-stand with one foot on each object and keep them horizontal

Level 3

- Square Wobble Board-maintain a horizontal position in the ML direction with FA

Level 4

- Square Wobble Board-maintain a horizontal position in the AP direction with FA

Level 5

- Square Wobble Board-maintain a horizontal position in the diagonal direction with FA

Level 6

- Square Wobble Board-maintain a horizontal position in the ML direction with FT

Level 7

- Square Wobble Board-maintain a horizontal position in the AP direction with feet in semi-tandem

Level 8

- Square Wobble Board-maintain a horizontal position in the diagonal direction with feet in semi-tandem

Level 9

- Square Wobble Board-maintain a horizontal position in the ML direction with feet in semi-tandem

Level 10

- Square Wobble Board-maintain a horizontal position in the AP direction with feet in semi-tandem

Level 11

- Square Wobble Board-maintain a horizontal position in the diagonal direction with feet in semi-tandem

Level 12

- Square Wobble Board-maintain a horizontal position in the ML direction with feet in tandem

Level 13

- Square Wobble Board-maintain a horizontal position in the AP direction with feet in tandem

Level 14

- Square Wobble Board-maintain a horizontal position in the diagonal direction with feet in tandem

Level 15

- Square Wobble Board-maintain a horizontal position in the ML direction on one foot

Level 16

- Square Wobble Board-maintain a horizontal position in the AP direction on one foot

Level 17

- Square Wobble Board-maintain a horizontal position in the diagonal direction on one foot

9. Circular Wobble Board

Level 1

- Circular Wobble board-rotate around the perimeter of the wobble board in one direction for 30 s then the other way for 30 s

Level 2

- Circular Wobble board-stand with FA and hold

Level 3

- Circular Wobble board-stand with FT and hold

Level 4

- Circular Wobble board-stand in semi-tandem and hold (alternate leading limb)

Level 5

- Circular Wobble board-stand in tandem and hold (alternate leading limb)

Level 6

- Circular Wobble board-stand on one foot and hold (alternate leading limb)

10. Stepper

Level 1

- Stepper-stepping onto and off of stepper 5 times with each leg in the anterior-posterior (AP) direction

Level 2

- Stepper-stepping onto and off of stepper 5 times with each leg in the medial-lateral (ML) direction

Level 3

- Stepper-stepping onto the stepper and marching 5 times, then off and repeat 5 times (both legs; AP)

Level 4

- Stepper-stepping onto the stepper and marching 5 times, then off and repeat 5 times (both legs; ML)

Level 5

- Stepper-walk around the perimeter on toes

Level 6

- V-step

Level 7

- Single knees

Level 8

- Hamstring curls

Level 9

- Single kicks

Level 11

- Tree pose (alternate feet)

Level 12

- Stepper-stork position (alternate feet)

Level 13

- Stepper-bring foot front, side and back as high as feasible (alternate feet)

11. Half-Foam Rollers

Level 1

- Half-Foam Rollers-side stepping flat side down with both rollers (do one direction then the other so that each foot leads)

Level 2

- Half-Foam Rollers-walking forwards flat side down

Level 3

- Half-Foam Rollers-walking grape vine flat side down (do one direction then the other so each foot leads)

Level 4

- Half-Foam Rollers-walking backwards flat side down

Level 5

- Half-Foam Rollers-side stepping one foam roller flat side up (do one direction then the other so that each foot leads)

Level 6

- Half-Foam Rollers-walking forwards one foam roller flat side up

Level 7

- Half-Foam Rollers-walking grape vine one foam roller flat side up (do one direction then the other so each foot leads)

Level 8

- Half-Foam Rollers-walking backwards one foam roller flat side up

Level 9

- Half-Foam Rollers-side stepping both foam rollers flat side up (do one direction then the other so that each foot leads)

Level 10

- Half-Foam Rollers-walking forwards both foam rollers flat side up

Level 11

- Half-Foam Rollers-walking grape vine both foam rollers flat side up (do one direction then the other so each foot leads)

Level 12

- Half-Foam Rollers-walking backwards both foam rollers flat side up

12. Balance Pods

Level 1

- Balance Pods-walk straight across balance pods (assembled staggered), try on tip toes, middle and heel of foot

Level 2

- Balance Pods-pods assembled mostly on right with some on left and participant must walk across (and vice versa)

Level 3

- Balance Pods-pods assembled in semicircle in front while standing on one pod behind on one foot. Participants must tap each pod in front, try with both feet.

Level 4

- Balance Pods-pods assembled in a circle and participant must walk around (one way then the other)

Level 5

- Balance Pods-pods assembled in a star shape and participant must walk around (one way then the other)

13. Seated Balance

Level 1

- Seated in a Chair-pick up ball from one side and put it to the other (try to keep legs off ground)

Level 2

- Seated in a Chair-jumping jacks

Level 3

- Seated in a Chair-cross hands across chest, lift right leg and twist torso to the right (alternate sides)

Level 4

- Seated in a Chair-hands extended above the head, right hand reaches left toe (alternate sides)

Level 5

- Seated in a Chair-legs and back extended, bring both feet and torso inwards simultaneously

Level 6

- Seated in a Chair-lean back, move legs in the “bicycle”, and move med ball from side to side

Level 7

- Seated Suisse-pick up ball from one side and put it to the other

Level 8

- Seated Suisse-jumping jacks

Level 9

- Seated Suisse-cross hands across chest, lift right leg and twist torso to the right (alternate sides)

Level 10

- Seated Suisse-hands extended above the head, right hand reaches left toe (alternate sides)

Level 11

- Seated Suisse-one leg and back extended, bring one feet and torso inwards simultaneously (alternate sides)

Level 12

- Seated Suisse-lean back, keep one leg off the ground, and move med ball from side to side (alternate sides)

APPENDIX 2: EXAMPLES OF MANUAL TASKS

The following are examples of manual dual-tasks that were performed in the BMT and BMT+C. There were no progressive levels for the manual tasks as the trainers selected appropriate exercises for the participants according to each individual's areas of weakness, and according to each individual's abilities.

- Bouncing a ball on the ground
- Balancing a bean bag on the head/hands
- Reaching and putting a bean bag on a foam roller (in front and on both sides)
- Moving a ball/bean bag around the body
- Figure 8 with a medicine ball
- Catch and throw a tennis ball/bean bag (underhand and overhand, make his harder by clapping and then catching, throwing with different heights and directions)
- Move a ball from floor to over the head (in front and on both sides)
- Tossing bean bags into a hula hoop
- Doing circles with a hula hoop on one arm
- Head, arms, and trunk twisting
- Changing the center of mass (i.e., tip toes to crouching down)
- Touching toes
- Carrying bags of different weights
- Carrying a clear or opaque box (opaque boxes reduce anterior vision)
- Carrying an opaque box with a tennis ball inside and moving the box such that the tennis ball stays around the perimeter
- Balancing bean bags on the back of the hands
- Balance a balance pod on a lid
- Randomly moving an object (in/out/up/down)
- Moving or holding a medicine ball away from the body

APPENDIX 3: COMPLETE LIST OF COGNITIVE TASKS AND LEVELS OF PROGRESSION

Stipulations for advancing in the Cognitive Task Level

1. No errors
2. No breaks in speech greater than 3-5 seconds
3. Participants cannot advance in a level during one session
4. Participants must perform the task successfully once before advancing

Cognitive tasks

1. N-Back Numbers
2. Letter Sequencing
3. Number Sequencing
4. N-Back Words
5. Counting Backwards
6. Conversation and Description on Request
7. Arithmetic Operations
8. Spelling to Dictation
9. Oral Spelling
10. Counting Forwards
11. Number Lists
12. Naming
13. Math Fluency

1. N-Back Numbers

Level 1

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a two-digit number sequence presented every 5 seconds

Level 2

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a two-digit number sequence presented every 3 seconds

Level 3

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a two-digit number sequence presented every 2 seconds

Level 4

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a three-digit number sequence presented every 5 seconds

Level 5

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a three-digit number sequence presented every 3 seconds

Level 6

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a three-digit number sequence presented every 2 seconds

Level 7

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a two-digit number sequence presented every 5 seconds

Level 8

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a two-digit number sequence presented every 3 seconds

Level 9

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a two-digit number sequence presented every 2 seconds

Level 10

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a three-digit number sequence presented every 5 seconds

Level 11

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a three-digit number sequence presented every 3 seconds

Level 12

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a three-digit number sequence presented every 2 seconds

2. Letter Sequencing

Level 1

- Track the number of times a given letter appears in a three-letter word sequence presented every 5 seconds in a recording

Level 2

- Track the number of times a given letter appears in a four-letter word sequence presented every 5 seconds in a recording

Level 3

- Track the number of times a given letter appears in a five-letter word sequence presented every 5 seconds in a recording

Level 4

- Track the number of times a given letter appears in a three-letter word sequence presented every 3 seconds in a recording

Level 5

- Track the number of times a given letter appears in a four-letter word sequence presented every 3 seconds in a recording

Level 6

- Track the number of times a given letter appears in a five-letter word sequence presented every 3 seconds in a recording

Level 7

- Track the number of times two given letters appear in a three-letter word sequence presented every 2 seconds in a recording

Level 8

- Track the number of times two given letters appear in a four-letter word sequence presented every 2 seconds in a recording

Level 9

- Track the number of times a given letter appears in a five-letter word sequence presented every 2 seconds in a recording

Level 10

- Track the number of times two given letters appear in a three-letter word sequence presented every 5 seconds in a recording

Level 11

- Track the number of times two given letters appear in a four-letter word sequence presented every 5 seconds in a recording

Level 12

- Track the number of times two given letters appear in a five-letter word sequence presented every 5 seconds in a recording

Level 13

- Track the number of times two given letters appear in a three-letter word sequence presented every 3 seconds in a recording

Level 14

- Track the number of times two given letters appear in a four-letter word sequence presented every 3 seconds in a recording

Level 15

- Track the number of times two given letters appear in a five-letter word sequence presented every 3 seconds in a recording

Level 16

- Track the number of times two given letters appear in a three-letter word sequence presented every 2 seconds in a recording

Level 17

- Track the number of times two given letters appear in a four-letter word sequence presented every 2 seconds in a recording

Level 18

- Track the number of times a given letter appears in a five-letter word sequence presented every 2 seconds in a recording

3. Number Sequencing

Level 1

- Track the number of times a random and audible two-digit number appears every 5 seconds

Level 2

- Track the number of times a random and audible two-digit number appears every 3 seconds

Level 3

- Track the number of times a random and audible two-digit number appears every 2 seconds

Level 4

- Track the number of times a random and audible three-digit number appears every 5 seconds

Level 5

- Track the number of times a random and audible three-digit number appears every 3 seconds

Level 6

- Track the number of times a random and audible three-digit number appears every 2 seconds

Level 7

- Track the number of times two random and audible two-digit numbers appear every 5 seconds

Level 8

- Track the number of times two random and audible two-digit numbers appear every 3 seconds

Level 9

- Track the number of times two random and audible two-digit numbers appear every 2 seconds

Level 10

- Track the number of times two random and audible three-digit numbers appear every 5 seconds

Level 11

- Track the number of times two random and audible three-digit numbers appear every 3 seconds

Level 12

- Track the number of times two random and audible three-digit numbers appear every 2 seconds

4. N-Back Words

Level 1

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a five-letter word sequence presented every 5 seconds

Level 2

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a five-letter word sequence presented every 3 seconds

Level 3

- At random time points when the trainer stops the recording, verbalize the second last word that appeared in a five-letter word sequence presented every 2 seconds

Level 4

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a five-letter word sequence presented every 5 seconds

Level 5

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a five-letter word sequence presented every 3 seconds

Level 6

- At random time points when the trainer stops the recording, verbalize the third last word that appeared in a five-letter word sequence presented every 2 seconds

Level 7

- At random time points when the trainer stops the recording, verbalize the fourth last word that appeared in a five-letter word sequence presented every 5 seconds

Level 8

- At random time points when the trainer stops the recording, verbalize the fourth last word that appeared in a five-letter word sequence presented every 3 seconds

Level 9

- At random time points when the trainer stops the recording, verbalize the fourth last word that appeared in a five-letter word sequence presented every 2 seconds

5. Counting Backwards

Level 1

- Given a random 3-digit number, count backwards by 2s

Level 2

- Given a random 4-digit number, count backwards by 2s

Level 3

- Given a random 3-digit number, count backwards by 4s

Level 4

- Given a random 4-digit number, count backwards by 4s

Level 5

- Given a random 3-digit number, count backwards by 3s

Level 6

- Given a random 4-digit number, count backwards by 3s

Level 7

- Given a random 3-digit number, count backwards by 6s

Level 8

- Given a random 4-digit number, count backwards by 6s

Level 9

- Given a random 3-digit number, count backwards by 9s

Level 10

- Given a random 4-digit number, count backwards by 9s

Level 11

- Given a random 3-digit number, count backwards by 7s

Level 12

- Given a random 4-digit number, count backwards by 7s

6. Conversation and Description on Request

Level 1

- Talk about a given topic for 1 minute

Level 2

- Talk about a given topic for 1 minute and add humor

Level 3

- Talk about a given topic for 1 minute and add humor and add a theme (e.g., trainer gives a specific setting, character, holiday, etc., that the participant must incorporate)

Level 4

- Talk about a given topic for 1 minute and add humor and add a theme (e.g., trainer gives a specific setting, character, holiday, etc., that the participant must incorporate)

Level 5

- Talk about a given topic for 1 minute and add humor and add a theme, and add a descriptive word (e.g., must use “tremendous” in the story)

Level 6

- Talk about a given topic for 1 minute and add humor and add a theme, and add a descriptive word, and participants must discuss their senses during the story (i.e., sight, hearing, touch, taste, smell)

7. Arithmetic Operations

Level 1

- Mentally perform a series of 15 simple mathematical equations presented at 4-second intervals in a recording (e.g. $5 - 3 + 10 \div 2$, etc.)

Level 2

- Mentally perform a series of 20 simple mathematical equations presented at 3-second intervals in a recording (e.g. $5 - 3 + 10 \div 2$, etc.)

Level 3

- Mentally perform a series of 30 simple mathematical equations presented at 2-second intervals in a recording (e.g. $5 - 3 + 10 \div 2$, etc.)

8. Spelling to Dictation

Level 1

- Spell and articulate the audible 3-letter word presented every 5 seconds forwards

Level 2

- Spell and articulate the audible 3-letter word presented every 3 seconds forwards

Level 3

- Spell and articulate the audible 3-letter word presented every 2 seconds forwards

Level 4

- Spell and articulate the audible 4-letter word presented every 5 seconds forwards

Level 5

- Spell and articulate the audible 4-letter word presented every 3 seconds forwards

Level 6

- Spell and articulate the audible 4-letter word presented every 2 seconds forwards

Level 7

- Spell and articulate the audible 5-letter word presented every 5 seconds forwards

Level 8

- Spell and articulate the audible 5-letter word presented every 3 seconds forwards

Level 9

- Spell and articulate the audible 5-letter word presented every 2 seconds forwards

Level 10

- Spell and articulate the audible 3-letter word presented every 5 seconds backwards

Level 11

- Spell and articulate the audible 3-letter word presented every 3 seconds backwards

Level 12

- Spell and articulate the audible 3-letter word presented every 2 seconds backwards

Level 13

- Spell and articulate the audible 4-letter word presented every 5 seconds backwards

Level 14

- Spell and articulate the audible 4-letter word presented every 3 seconds backwards

Level 15

- Spell and articulate the audible 4-letter word presented every 2 seconds backwards

Level 16

- Spell and articulate the audible 5-letter word presented every 5 seconds backwards

Level 17

- Spell and articulate the audible 5-letter word presented every 3 seconds backwards

Level 18

- Spell and articulate the audible 5-letter word presented every 2 seconds backwards

9. Oral Spelling

Level 1

- Name as many words as possible given the letters from a particular given word

Level 2

- Name as many words as possible in alphabetical order forwards from a particular given word (e.g., Tablecloth: a; able; bat; bet, etc.),

Level 3

- Name as many words as possible in alphabetical order backwards from a particular given word (e.g., Tablecloth: that; table; tab; let, etc.)

Level 4

- Name as many words as possible in alphabetical order forwards and repeat the previous word(s) in the list from a particular given word (e.g., Tablecloth: a; a, able; a, able, bat; a, able, bat, bet, etc.)

Level 5

- Name as many words as possible in alphabetical order backwards and repeat the previous word(s) in the list from a particular given word (e.g., Tablecloth: that; that, table; that, table, tab; that, table, tab, let, etc.)

10. Counting Forwards

Level 1

- Count forwards by 2s given a random 3-digit number

Level 2

- Count forwards by 2s given a random 4-digit number

Level 3

- Count forwards by 4s given a random 3-digit number

Level 4

- Count forwards by 4s given a random 4-digit number

Level 5

- Count forwards by 3s given a random 3-digit number

Level 6

- Count forwards by 3s given a random 4-digit number

Level 7

- Count forwards by 6s given a random 3-digit number

Level 8

- Count forwards by 6s given a random 4-digit number

Level 9

- Count forwards by 7s given a random 3-digit number

Level 10

- Count forwards by 7s given a random 4-digit number

11. Number Lists

Level 1

- Listen to and remember 3 single-digit numbers presented every 5 seconds. These numbers will be repeated in the same order, except one of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 2

- Listen to and remember 3 single-digit numbers presented every 5 seconds. These numbers will be repeated in the same order, except two of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 3

- Listen to and remember 3 single-digit numbers presented every 3 seconds. These numbers will be repeated in the same order, except one of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 4

- Listen to and remember 3 single-digit numbers presented every 3 seconds. These numbers will be repeated in the same order, except two of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 5

- Listen to and remember 3 double-digit numbers presented every 5 seconds. These numbers will be repeated in the same order, except one of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 6

- Listen to and remember 3 double-digit numbers presented every 5 seconds. These numbers will be repeated in the same order, except two of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 7

- Listen to and remember 3 double-digit numbers presented every 3 seconds. These numbers will be repeated in the same order, except one of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 8

- Listen to and remember 3 double-digit numbers presented every 3 seconds. These numbers will be repeated in the same order, except two of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 9

- Listen to and remember 3 triple-digit numbers presented every 5 seconds. These numbers will be repeated in the same order, except one of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 10

- Listen to and remember 3 triple-digit numbers presented every 5 seconds. These numbers will be repeated in the same order, except two of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 11

- Listen to and remember 3 triple-digit numbers presented every 3 seconds. These numbers will be repeated in the same order, except one of the numbers will be verbalized as “blank” You must remember which number was a “blank”

Level 12

- Listen to and remember 3 triple-digit numbers presented every 3 seconds. These numbers will be repeated in the same order, except two of the numbers will be verbalized as “blank” You must remember which number was a “blank”

12. Naming

Level 1

- Name as many words as possible in a given category

Level 2

- Name as many words as possible in alphabetical order forwards in a given category (e.g., Fruit: apple, banana, blackberry, blueberry, etc)

Level 3

- Name as many words as possible in alphabetical order backwards in a given category (e.g., Vegetables: zucchini, yam; watercress; etc)

Level 4

- Name as many words as possible in alphabetical order forwards in a given category and repeat the previous word(s) in the list (e.g., Sports: archery; archery, badminton; archery, badminton, cricket, etc)

Level 5

- Name as many words as possible in alphabetical order backwards in a given category and repeat the previous word(s) in the list (e.g., Flowers: zenobia; zenobia, yellow-eyed grass; zenobia, yellow-eyed grass, waterlily, etc)

13. Math Fluency

Level 1

- Guess the trainer's 2-digit number (i.e., numbers between 10-99)

Level 2

- Guess the trainer's random 3-digit number (i.e., numbers between 100-999)

Level 3

- Guess the trainer's random 4-digit number (i.e., numbers between 1000-9999)

Level 4

- Guess the trainer's random 5-digit number (i.e., numbers between 10000-99999)

Level 5

- Guess the trainer's random 6-digit number (i.e., numbers between 100000-999999)

*Participant must guess each digit, and the trainer informs the participant which digits are higher, lower, or the same as their number.

APPENDIX 4: COMPARISON OF RT ACROSS STUDIES 1-2 AND EXPERIMENTS 4-5

Mean ± SD (s) of RT over time for the BMT, BMT+C, Control, and Preliminary Study groups.

Group	Baseline				Group	Effect of time				Group	Baseline - Effect of time			
	Standing SRT	Standing CRT	Obstacle Clearance SRT	Obstacle Clearance CRT		Standing SRT	Standing CRT	Obstacle Clearance SRT	Obstacle Clearance CRT		Standing SRT	Standing CRT	Obstacle Clearance SRT	Obstacle Clearance CRT
BMT	0.417 ± 0.067	0.587 ± 0.065	0.405 ± 0.064	0.534 ± 0.109	12-week BMT	0.369 ± 0.050	0.528 ± 0.077	0.355 ± 0.054	0.458 ± 0.082	BMT	0.048 + 0.017	0.059 - 0.012	0.050 - 0.010	0.076 + 0.027
BMT+C	0.384 ± 0.066	0.534 ± 0.096	0.353 ± 0.049	0.494 ± 0.107	12-week BMT+C	0.339 ± 0.050	0.512 ± 0.109	0.321 ± 0.046	0.440 ± 0.081	BMT+C	0.045 + 0.016	0.022 + 0.013	0.032 + 0.003	0.054 + 0.026
Control	0.383 ± 0.050	0.535 ± 0.076	0.383 ± 0.050	0.499 ± 0.086	12-week Control	0.403 ± 0.071	0.519 ± 0.085	0.381 ± 0.049	0.494 ± 0.094	Control	-0.020 - 0.021	0.016 - 0.09	0.002 + 0.001	0.005 - 0.008
Preliminary Study	0.347 ± 0.062	0.513 ± 0.75	0.380 ± 0.069	0.494 ± 0.102	5-week Preliminary Study	0.335 ± 0.063	0.425 ± 0.093	0.300 ± 0.045	0.363 ± 0.045	Preliminary Study	0.012 + 0.001	0.088 - 0.018	0.080 + 0.024	0.131 + 0.057

APPENDIX 5: NOTICE OF ETHICAL APPROVAL FOR STUDIES 1-3

File Number: H12-13-04

Date (mm/dd/yyyy): 01/08/2014



Université d'Ottawa **University of Ottawa**
 Bureau d'éthique et d'intégrité de la recherche Office of Research Ethics and Integrity

Ethics Approval Notice Health Sciences and Science REB

Principal Investigator / Supervisor / Co-investigator(s) / Student(s)

<u>First Name</u>	<u>Last Name</u>	<u>Affiliation</u>	<u>Role</u>
Deborah	Jehu	Health Sciences / Human Kinetics	Principal Investigator
Yves	Lajoie	Health Sciences / Human Kinetics	Supervisor

File Number: H12-13-04

Type of Project: Other

Title: Examining the stability of balance measures, functional measures, and psychological measures over time in older adults

Approval Date (mm/dd/yyyy)	Expiry Date (mm/dd/yyyy)	Approval Type
01/08/2014	01/07/2015	Ia

(Ia: Approval, Ib: Approval for initial stage only)

Special Conditions / Comments:

N/A

APPENDIX 6: NOTICE OF ETHICAL APPROVAL FOR EXPERIMENTS 3-5

File Number: H12-13-04B

Date (mm/dd/yyyy): 05/06/2014



Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

Ethics Approval Notice**Health Sciences and Science REB****Principal Investigator / Supervisor / Co-investigator(s) / Student(s)**

<u>First Name</u>	<u>Last Name</u>	<u>Affiliation</u>	<u>Role</u>
Yves	Lajoie	Health Sciences / Human Kinetics	Supervisor
Nicole	Pasquet	Health Sciences / Human Kinetics	Co-Supervisor
Deborah	Jehu	Health Sciences / Human Kinetics	Student Researcher

File Number: H12-13-04B**Type of Project:** PhD Thesis**Title:** The effect of dual-task training on dual-task abilities in older adults

<u>Approval Date (mm/dd/yyyy)</u>	<u>Expiry Date (mm/dd/yyyy)</u>	<u>Approval Type</u>
05/06/2014	05/05/2015	Ia

(Ia: Approval, Ib: Approval for initial stage only)

Special Conditions / Comments:

N/A