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Linking Cognitive Load, Perception, and Postural Sway in Older Adults

By

Shawn R. Reaume

A Thesis  
Submitted to the Faculty of Graduate Studies  
through the Faculty of Human Kinetics  
in Partial Fulfillment of the Requirements for  
the Degree of Master of Human Kinetics  
at the University of Windsor

Windsor, Ontario, Canada

2017

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Linking Cognitive Load, Perception, and Postural Sway in Older Adults

by

Shawn R. Reaume

APPROVED BY:

---

L. Buchanan  
Department of Psychology

---

P. van Wyk  
Faculty of Human Kinetics

---

Nancy McNevin, Advisor  
Faculty of Human Kinetics

December 15, 2017

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## ABSTRACT

Falls in older adults put a great strain on Canadians in monetary terms and quality of life. Traditional motor theory proposes that declining systems crucial for balance along with reduced cognitive capacity are reasons for a high incidence in falls. However, this does not account for individual differences in perceptions of fallers vs. non-fallers. This exploratory study aimed to find an action-perception uncoupling in older adults at risk for falling to account for deficits in motor control. 21 healthy male and female adults with a mean age of 67.7 years were separated into Control of Fear of Falling groups. Participants stood on a force platform, completed various levels of cognitive tasks, and inspected several images of everyday outdoor environments of varying levels of difficulty to navigate, all while biofeedback and eye-tracking were being measured. Six 2(Group) \* 3(Condition) mixed factorial ANOVAs with repeated measures and a correlation matrix to compare conditions were run. Results showed only significant main effects for heart rate  $F(2,18) = 29.817, p = .000 < .05, \eta^2 = .768$ , pupil size  $F(2,18) = 4.743, p = .022 < .05, \eta^2 = .345$ , and mean moving window  $F(2,18) = 10.918, p = .001 < .05, \eta^2 = .548$  under cognitive load conditions. Encouraging insignificant differences between groups were observed, but a small sample size and unequal groups did not supply enough power to detect them.

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## NOMENCLATURE

**Balance:** An even distribution of weight enabling someone or something to remain upright and steady (Oxford University Press, n.d.)

**Fall:** to leave an erect position suddenly and involuntarily (Merriam-Webster, Incorporated, n.d.); to suddenly go down onto the ground or towards the ground without intending to or by accident (Cambridge University Press, n.d.); (of a person) lose one's balance and collapse (Oxford University Press, n.d.)

**Postural Control:** An involuntary neurological loop consisting of motor, sensory, and integrative processes used to maintain the body's position relative to gravity and of its segments relative to each other for stability. Postural control relies on information from the vestibular and somatosensory systems and visual cues (Medical Dictionary, n.d.)

**Postural Sway:** in terms of human sense of balance, refers to horizontal movement around the center of gravity. This sway is essential due to the many large and small changes in the center of gravity due to functions such as walking and breathing (AlleyDog.com, n.d.)

**Posture:** the position or bearing of the body whether characteristic or assumed for a special purpose (i.e. erect posture when sitting or standing) (Merriam-Webster, Incorporated, n.d.)



stability: the property of a body that causes it when disturbed from a condition of equilibrium or steady motion to develop forces or moments that restore the original condition (Merriam-

## CHAPTER 1

### INTRODUCTION

#### *Costs Associated with Falls*

In "The Cost of Injury in Canada" (Parachute, 2015), an updated report to *The Economic Burden of Injury in Canada* from 2009, is a report on the country's causes of injuries, all costs associated with them, and which age groups were affected based on statistics gathered in 2010. Falls were the leading cause of deaths, hospitalizations, permanent partial disability, and permanent total disability; and were second only to other "unintentional injuries" in the category of emergency room visits. The incidence of falls and associated injuries was greater than all other injuries, including transport incidents, suicide/self-harm, accidental injuries, and violence, to name a few. In terms of monetary cost, falls among men and women aged 65+ years accounted for 3369 (\$ Millions) per year, and had the highest per capita cost for age groups 75-84 and 85+ years with 793.41 and 1974.45 (\$ Millions), respectively. Additionally, the rates of falls among adults aged 65+ years was far and above those of the rest of the population in all categories. Women had a much higher incidence of being hospitalized and visiting the emergency room than men as a result of a fall, whereas men had higher death rates from falls than women (Parachute, 2015; CDC, 2009). It is suspected that the higher prevalence of osteoporosis among women is the cause for the more frequent hospitalization than men (CDC, 2009).

Statistics Canada (2016) reveals a trend in their report titled *Canadian Population at a Glance*, which indicated that as of 2013, Canadians aged 65+ years represented a record proportion of the population. Due to the lengthening of life expectancy and below-replacement fertility, this demographic encompassed 15.3% of the Canadian population

at 5.4 million and was projected to exceed the proportion of children in 2017 (StatsCan, 2016). Knowing then, that the costs associated with caring for the older population exists and will likely continue to rise, serious efforts to address falls have been undertaken. The "Canadian Falls Prevention Curriculum" (CFPC) is one such program designed specifically to teach its participants strategies to prevent falls and fall-related injuries in the older population (CFPC, 2017).

In addition to the monetary strain on healthcare services associated with falling, there is a human cost in terms of loss of enjoyment of life as a result of injuries. In a review on the psychological outcomes of falling, Jorstad, Hauer, Becker, and Lamb (2005) noted several interrelated negative issues as a consequence of falling. Older adults who have fallen often develop a fear of falling, which is a psychological condition akin to anxiety related to having fallen or experiencing future falls (Legters, 2002), which can lead to activity restriction and avoidance (Jorstad et al., 2005). Whereas someone may have enjoyed regular family gatherings, social meetings, or a physically active lifestyle, a newly obtained fear of falling and its consequences could greatly impact a person's willingness to further engage in such activities. Similarly, a loss of confidence or efficacy can stem from falling such that the individual may lose confidence in his or her ability to perform activities of daily living (ADL), and will begin to do less of what they used to enjoy (Jorstad et al., 2005). Fear, loss of confidence and efficacy, and activity avoidance are compounding factors that can quickly reduce a person's quality of life, which can be described by five categories: normal life, happiness/satisfaction, achievement of personal goals, social utility, and natural capacity (Ferrans, 1990; Jorstad et al., 2005). These

reductions in activities can then lead to a loss of independence, which is correlated with a higher incidence of death (Hirvensalo, Rantanen, and Heikkinen, 2000).

Loss of independence can be difficult for some older adults, who may not feel comfortable placing such a burden on loved ones (Bertera and Bertera, 2008). In Canada in 2012, an estimated 27% of persons aged 15-29 years provided some sort of care to a family member or friend who had fallen, with 19% providing care to two or more people. Whereas most found the experience rewarding, one third of these young caregivers reported feeling worried, anxious, or tired, while one fifth reported care-giving had adversely affected their schooling (Bleakney, 2014). Because the impact of falls affects so many people, identifying why older adults fall repeatedly is crucial in helping a large portion of the Canadian population maintain a better quality of life.

### *Why Older Adults Fall*

Falls among older adults are due to a number of reasons, as well as the combination of several different factors. Normal changes associated with aging often lead to declines in overall muscle strength, which lead to changes in balance, stepping efficiency, and slower reactions to loss of balance (Brouwer, Musselman, and Culham, 2004). Frank and Patla (2003) report a large amount of evidence showing muscular strength declines with age in both number and size of muscle fibres and even liken the effects of these declines, in combination with vestibular function declines, to 20 days of bed rest for a young adult. A study by Hurley, Rees, and Newham (1998) found age-related differences in quadriceps strength and proprioceptive acuity, which is an important feedback system for mobility in general. Shaffer and Harrison (2007) suggest

that that there may be age-related changes to the muscle spindles and Golgi tendons, which both provide proprioceptive feedback about joint movement and load.

At the same time, it is not uncommon for older adults to experience impairments in vision and hearing, which can contribute to a reduced environmental awareness (Kulmala et al., 2009). Additionally, there is a tendency for age-related declines in cognitive abilities associated with performing mental tasks while maintaining balance (Nagamatsu et al., 2011; St. George, Fitzpatrick, Rogers, van Donkelaar, & Woollacott, 2007). Older adults appear to have less cognitive resources available for dividing attention between secondary tasks and maintaining balance while standing or walking, and this can negatively affect balance as well as the secondary task, as they often prioritize stability (Li, Lindenberger, Freund, & Baltes, 2001; Melzer, Liebermann, Krasovsky, & Oddsson, 2010). Additionally, some older adults may possess or can develop a fear of falling. With so many fall-related factors associated with aging, the high prevalence of falls in older adults comes as no surprise. The combination of these factors has the greatest impact on postural control and gait.

### *Normal Postural Control*

All of these factors must be recognized and attended to by the body's respective systems simultaneously in order to maintain balance in everyday situations, which means there is large amount of background processes working during normal postural control at all times. Normal postural control is actually a complex skill based on the interaction of dynamic sensorimotor processes instead of just static reflexes (Horak, 2006). It is a delicate interplay between several systems, including the visual, vestibular, and

somatosensory systems, and this interplay can vary depending on the unique characteristics of individuals or environmental circumstances or demands (Mahboobin, Loughlin, Redfern, & Sparto, 2005). Although some may consider postural control to be automatic and require little or no conscious control, it does require some. In other words, postural control is a system's response to inputs and resistance to change, and those responses require cognitive effort (Riccio & Stoffregen, 1988). Recall that postural deficits depend on the degree of decline in muscle strength, vision, and hearing, and the fact that there are different processes involved in maintaining posture. Because of the complex interaction of systems, there is an inherent flexibility in systems for maintaining posture called “sensory reweighting”.

### *Sensory Reweighting and Vision*

Sensory reweighting is the adaptive process of determining the reliability and importance of some sensory information over other sensory information based on an environmental change (Jeka, Allison, & Kiemel, 2010). The model attempts to explain how and why some senses are dominant over other senses under different circumstances. A simple example would be navigating an unfamiliar room in the dark; with little or no vision, reliance on touch and hearing becomes amplified. Studies have been done to investigate the sensory reweighting hypothesis (Mahboobin et al, 2005; Jeka et al, 2010; Berard, Fung, & Lamontagne, 2012; Pradels, Pradon, Hlavackova, Diot, & Vuillerme, 2013), in which experimentally induced changes to postural control were used to determine if the importance of some sensory information will change when other sources are compromised by aging. It was suggested that slowed sensory reweighting and

postural adjustments are contributing factors to falls in fall-prone adults. For example, older adults were slower to prepare movements in response to stimuli (Canavan, Lutzenberger, & Bayer, 1993). Mulder, Zijlstra, & Geurts (2002) propose that there is a cost associated with compensation, and that the deteriorating motor system can be somewhat rectified by shifts to other, slower control strategies.

It has also been shown that reliance on visual information for maintaining balance can become stronger or weaker depending on the type of changes induced, and that older adults tend to rely more heavily on vision than younger adults. Because vision plays a critical role in postural control, and vision declines with aging, there likely exists a link between visual impairment and the likelihood of falling in older adults (Brundle et al., 2015). Older adults have a slower adaptive visual reweighting process than younger adults, which leads to slowed time in making postural adjustments (Jeka et al, 2010; Berard et al, 2012). In a study comparing high and low risk of falling older adults involving stepping over obstacles, Chapman and Hollands (2006) found that when a single obstacle was presented, there were no differences. However, when a second stepping target was introduced, high-risk participants transferred their gaze significantly sooner from the first obstacle to the second, which lead to a decline in stepping accuracy and precision over the first obstacle. This suggests that high-risk adults feel the need to plan future stepping sooner, perhaps due to a lack of confidence or from perceiving the second obstacle as a threat to stability. This planning likely requires increased cognitive resources and a conscious change in focus (Chapman & Hollands, 2006). Similarly, Zietz and Hollands (2009) found that older adults fixated on stairs significantly longer than younger adults before stepping onto them, again suggesting that vision is relied on more

heavily as a source of environmental information as we age, despite often being a system in decline. Cinelli, Patla, and Stuart (2008) found that the presence of a visual target greatly assisted older adults in maintaining postural stability. When compared to younger adults, older adults had earlier eye onset movements during gaze reorientation tasks, suggesting a greater reliance on visual information than their younger counterparts. This is likely a compensatory response as a result of decreased somatosensory system function (Cinelli et al., 2008). Vision, declines in vision, and declines in somatosensation are believed to be the strongest contributing factors to differences in successful stair negotiation between older and younger adults (Startzell, Owens, Mulfinger, & Cavanagh, 2000) and that older adults rely more heavily on visual information to provide information than do young adults in stair negotiation (Cromwell & Wellmon, 2001). The finding that vision is a heavily used source of information for maintaining postural stability among older adults and coupled with a slower reweighting process, implies that visual impairments are associated with poorer postural control (Lord, Clark, & Webster, 1991; Ivers, Cumming, Mitchell, & Attebo, 1998; Lord & Dayhew, 2001). These difference between visual and planning strategies often come at a cost, as noted by Chapman and Hollands (2006), and that cost is increased cognitive resources or load.

### *Cognitive Load and Postural Control*

Traditionally, it is said that there is a component of cognitive resources involved in balance and that these resources are limited (Kerr, Condon, & McDonald, 1985). For example, Lajoie, Teasdale, Bard, and Fleury (1993) had young adult participants, aged 30 - 40 years sitting, standing, and walking while responding to an auditory cue. They



concluded, based on reaction time to the auditory cues, that sitting requires less cognitive resources than standing, and that both require less than walking. Based on research by Teasdale et al. (1992) and Woollacott, Shumway-Cook, and Nashner (1986) (as cited by Mulder et al., 2002), shifts in control strategies by older adults cause postural adjustments to require cognitive processing. This is further supported by the works of Teasdale et al., (1992) and (as cited by Mulder et al., 2002) in which older participants' capacity to adapt to rapidly changing postural conditions were impaired. Many studies assessing the allocation of attentional and/or cognitive resources to postural control have used a dual-task experimental design. Briefly, dual-task paradigms have participants complete a primary motor task, such as static balance, while performing a secondary cognitive task, such as counting backwards from 100 by 3's (Woollacott & Shumway-Cook, 2002). This method can reveal significant gait or balance impairments when a cognitive load is introduced, suggesting postural control is not an automatic process. Postural control requires at least some cognitive intervention, and a dual-task manipulation can supposedly indicate the interference between processes and the degree of shared attention based on the extent of the decline in performance of either task (Kerr et al. 1985).

Furthermore, not all cognitive tasks are equally demanding. Kerr et al. (1985) had young adults perform a visual/spatial task or a non-spatial verbal memory task while seated, and again during a balance task on a force platform while blindfolded. The visual spatial task required participants to place numbers in imagined matrices and then remember the numbers' positions, which is known as the Brooks spatial memory task. The non-spatial verbal memory task required similar sentences to be remembered. Results showed that simultaneously performing the balance task and the spatial task

caused more errors in the spatial task itself compared to when seated, whereas the non-spatial task did not suffer. Postural sway was not significantly affected in either condition. This was the first study to conclude that postural control is attentionally demanding in young adults when coupled with secondary tasks that shared the same resources. Similarly, Maylor and Wing (1996) had two groups of participants with mean ages of 57 and 77, respectively, perform five different cognitive tasks while standing on a force platform. The goal was to identify which, if any, of the tasks caused greater interference with postural stability. The five tasks were: random digit generation, the Brook's spatial memory task, backward digit recall, silent counting, and counting backward in threes. Results showed that postural stability was adversely affected by all conditions in both groups, but even more so in the older group by the Brooks' spatial memory task and the backward digit recall. These results suggested that there exist age differences in the ability to divide attention, and that visuo-spatial tasks may share similar cognitive resources with postural control.

Evidence for age differences in the ability to divide cognitive resources is present in a multitude of dual-task studies with very similar results (Chen et al., 1996; Shumway-Cook et al., 1997; Lindenberger, Marsiske, and Baltes, 2000; Brown, Sleik, Polych, and Gage, 2002; Rapp, Krampe, and Baltes, 2006) in which older adults tended to prioritize stability over secondary cognitive tasks when compared to younger adults. A study by Li, Lindenberger, Freund, and Baltes (2001), which clearly outlines this effect, had older and younger adults follow a walking track with a handrail that included stepping obstacles. A conductive glove was worn to measure handrail contact time while 16 words were verbally presented to participants for 10 seconds per word in succession, with the goal of

recalling at least 12. Participants were also given the option of a memory aid to delay the presentation of the next word for three seconds by pressing a button in their other hand. Older adults opted to reach for a handrail to maintain balance while negotiating obstacles, while younger adults opted to use the memory aid to better perform the secondary task (Li et al., 2001). This effect in older adults is termed the "posture first" principle, such that as balance demands increase, more attention is diverted to meet them (Lion et al. 2014). Overall, when compared to young adults, older adults tend to have longer reaction times with divided attention (Gage, Sleik, Polych, McKenzie, & Brown, 2003), have a reduced ability to flexibly allocate attention between obstacles and secondary tasks (Siu, Chou, Mayr, van Donkelaar, & Woollacott, 2008), have increased postural sway as cognitive demands increase (Huxhold, Li, Schmiedek, & Lindenberger, 2005), increased time in muscle recruitment during the preparation and swing phases of their gait cycle (Melzer et al., 2010), and make more stepping errors as well as secondary task errors (St. George et al., 2007).

Additionally, when comparing healthy older adults with older adults that are balance-impaired or at risk for falls in dual-task studies, it was found that balance recovery was slower and less efficient in the at-risk group when performing a cognitive task (Brauer, Woollacott, & Shumway-Cook, 2001; Brauer, Woollacott, & Shumway-Cook, 2002) and that walking speed was slower and resulted in more collisions in a distracted walking task compared to their healthy counterparts (Nagamatsu et al., 2011). St. George et al. (2007) showed that at-risk older adults made significantly more stepping errors, obstacle contacts, and secondary task errors than their non at-risk counterparts in a stepping task. In a sentence completion and visual perception matching task study by

Shumway-Cook, Woollacott, Kerns, and Baldwin (1997), postural stability in the at-risk-of-falling older adult group was significantly affected by both conditions, whereas the healthy older adult group was not. Shumway-Cook & Woollacott (2000) also found that in a study where healthy older adults' postural sway was only affected by the two most difficult sensory conditions while performing a secondary auditory task, while older adults with a history of imbalance of falls were affected by all conditions

However, not all cognitive loads are detrimental to balance. Deviterne, Gauchard, Jamet, Vancon, and Perrin (2005) had older adults stand stationary on a force platform surrounded by speakers and attend to auditory cues occurring sequentially around them in a circular motion. Condition one had a meaningless singular pitch and the auditory cue. Condition two was a meaningful 20 second short story. In the meaningful condition, postural sway was actually reduced compared to the meaningless condition, despite having to commit more cognitive resources to track the sound as well as interpret it (Deviterne, et al., 2005). Across all age groups, study results showing no detrimental effects of cognitive loads on balance (Barra, Bray, Sahni, Golding, and Gresty, 2006; Kelly, Schragger, Price, Ferrucci, and Shumway-Cook, 2008) and even improving balance (Verrel, Lovden, Schellenbach, Schaefer, and Lindenberger, 2009; Fraser, Li, DeMont, and Penhune, 2007; Hunter and Hoffman, 2001; Mitra, Knight, and Munn , 2013; Matherton, Qing, Delpit-Baraut, Dailly, and Kapoula, 2015) are not uncommon.

Knowing that in general, attending to a secondary task can undermine balance, one might expect that the best way to maintain balance would be to focus on it instead of the secondary task. However, Andersson, Hagman, Talianzadeh, Svedberg, and Larsen (2002) found that in one of their experiments, the cognitive task reduced postural sway

among young adult participants, while focused attention did not, suggesting that focusing on balance does not always improve it. Similar results were found by Yeh, Boulet, Cluff, and Balasubramaniam (2010), where postural sway for young adult participants was increased by imposing visual feedback on a screen in the form of a white dot that corresponded to their centre of pressure, which was to be positioned as close to a target red dot as possible. Postural sway was reduced with the introduction of a low to moderately difficult cognitive arithmetic task, wherein participants performed six randomized additions or subtractions. It was suggested by Yeh et al. that dividing of attention between monitoring balance and performing a cognitive task may actually have induced an automatic balance response, whereas focusing on balance alone may disrupt it.

Such attentional focus can also be a factor in maintaining normal postural sway. McNevin and Wulf (2002) showed that when comparing postural sway of participants under an external and internal attentional focus condition, the external group tended to have improved static balance responses. The conditions required participants to stand still and lightly touch a sheet hanging in front of them. Under internal focus conditions, participants were instructed to minimize movements of their finger on a sheet they were lightly touching, while under external focus conditions, they were instructed to minimize movements of the sheet as a result of their touch (McNevin & Wulf, 2002). Both conditions were performed without vision, so participants were required to rely on proprioception while maintaining their balance and minimizing movements of their fingers. To account for the differences in postural control despite the small shift in attentional focus, McNevin and Wulf (2002) suggested that internal focus instructions

prompted participants to invest at least some cognitive processes in maintaining balance, which disrupted postural control. As an extension of those findings, postural instability in older adults who compensate by investing cognitive effort into maintaining postural control is expected to exacerbate those postural instabilities. This instability may also be further exaggerated by individuals whose fear of falling leads them to focus their attention on not falling, especially for those who are at a greater risk of falling.

Furthermore, a conscious effect to minimize postural sway may have unwanted consequences. Balasubramaniam, Riley, and Turvey (2000) conducted a handheld laser pointer task coupled with static balance. Participants were required to stand on a force platform and hold a laser pointer in their right hands with their arms at their side, with the laser pointer held against their right thighs. The goal was to keep the laser pointed at a fixed target as accurately as possible over 30 second trials. The first experiment had participants oriented so that the target was directly in front of them, albeit off-centered to the right. In the second experiment, a similar condition had the participants oriented so that the target was on their right side, thus the laser had to be pointed laterally instead of anteriorly. It was found that in the first experiment, participants had to limit their medio-lateral postural sway, but in doing so, increased their antero-posterior sway. Likewise, in the second experiment, antero-posterior sway was decreased with an increase in medio-lateral sway. These results suggested that there is an “optimal” amount of postural sway variability during quiet standing and that restricting movement in one direction causes an automatic increase in the other to maintain a constant amount of sway variability. This variability was thought to be an adaptive response to environmental perturbations.

### *Perception-Action Link/ Uncoupling*

Postural control is primarily an automatic response to perturbations. While vision is important, it carries a heavy cognitive load which can interfere with automatic control processes. This has been the traditional approach of information-processing models to account for changes in postural control. An alternative perspective, which acknowledges the important role of vision in maintaining posture, also incorporates the processes associated with motor control and proposes an interactive model, and is referred to as "direct perception". While information-processing models attribute changes in or loss of balance to information overload, they do not account for deficits in motor control. Information-processing proposes a "top-down" type of control, where the brain is the executive process which uses perceptions, existing motor programs, and feedback to coordinate the actions of the body beneath it. However, in the instances where cognition is so heavily loaded that there is little or no attention left to attend to maintaining posture, there must be some other control mechanism responsible for maintaining it.

Direct perception theory suggests the existence of a "bottom-up" aspect process, wherein actions directly affect perceptions. As described by Greeno (1994), Gibson (1979; as cited by Greeno, 1994) developed an interactionist approach, where perception drives action and action drives perception. Known as Gibson's "affordances", this theory suggested that every individual has a unique perspective on his or her environment that is a direct result of his or her own "body-scaled" characteristics. Gibson suggested, based on Greeno's interpretation, that every object in the environment presents the opportunity or affordance to engage in one or more actions based on the observer's individual perceptions, and those perceptions were scaled to that individual's intrinsic capabilities

(i.e., based on their height, strength weight, etc.). Turvey (1992) further expanded on Gibson's affordances by stating that successful action requires prospective control. Prospective control suggests that in order to plan future actions, it is essential to know which movement possibilities are viable options, and which are not. Furthermore, Turvey (1992) suggested that affordances are individual but must be based on actualizing circumstances, such that a predator would not afford danger to its prey unless it was within a critical proximity. Therefore, the perceiver must be capable of physically completing the action which it is being afforded within the situation that affords it. It is generally agreed upon that a perceiver and an environment are necessary for the existence of an affordance, and that a strong characteristic of how affordances are perceived are physical attributes, or body-scaled awareness.

Body-scaled awareness is a proposed method of analysis for affordances, and describes an organism-environment system that uses intrinsic measurements, such as eye height, leg length, or shoulder width, to navigate one's surroundings (Warren, 1984; Warren & Whang, 1987). Examples of affordances were first demonstrated in Warren's (1984) three riser height experiments. In the first experiment, Warren proposed that there should exist a constant body-scaled ratio between subjects' leg length and the riser height of stairs. To test this, he had participants view slides of stairs of differing riser heights and make individual judgements on their climbability. Naturally, taller participants rated more risers as climbable than did shorter participants; however, when observing the height at which a riser was rated as unclimbable, participants consistently rated risers as unclimbable at a ratio of .89 of riser height/ leg length. This is known as a critical point; a point where one action (stepping) is no longer feasible and a transition to a new



movement type is required, such as using all fours to climb. In the second experiment, Warren sought to determine if participants selected a riser height that corresponded to the most energy efficient action required to climb it, and had shorter and taller participants negotiate a series of steps that varied in riser height. Participants were required to navigate many different stair heights over 19 days while tracking O<sub>2</sub> inspired and CO<sub>2</sub> expired. Warren predicted an optimally energy efficient ratio would emerge between riser height/leg shank length, such that too low of a riser height would require more steps to negotiate, while too high of a riser height would require greater muscle strength and hip and knee flexion; both yielding higher than necessary energy expenditures overall. Results showed that the optimal riser height to shank length ratio for optimal energy expenditure was .26, regardless of participant height. Warren referred to this ratio as an optimal point. Finally, in his third experiment, Warren had taller and shorter participants view slides of differing riser heights again, and this time they were asked to identify what would be the most comfortable to ascend at a comfortable speed. Not surprisingly, regardless of height, the chosen riser height corresponded to a ratio of .25 of riser/shank length, which was very close to the metabolically optimal point ratio of .26 (Warren, 1984). The latter experiment suggested that we are able to identify energy efficient paths from energy inefficient ones prior to interacting with them; implying that our perception is based on our unique physical characteristics and abilities – essentially supporting a direct link between our perception and action capabilities.

Warren & Whang (1987) further expanded on the notion of affordances by identifying the types information utilized by the actor in these dynamic situations: intrinsic information and extrinsic information. Intrinsic information identifies

environmental dimensions relative to the dimensions of the perceiver in some type of body-scaled units, as demonstrated by Warren's (1984) riser height research. Extrinsic information, however, specifies the absolute dimensions of the environment in terms of an arbitrary metric (Warren & Whang, 1987). This suggests that once a spatiotemporal representation of the environment is gathered, it is compared with knowledge of the perceiver's motor abilities or body dimensions to create potential actions. In their experiment, smaller and larger subjects walked through apertures of varying widths (without seeing the width changes), and a critical point of aperture to shoulder width ratio of 1.30 was found, at which subjects spontaneously adjusted (by turning sideways) to walk through the aperture. Additionally, when smaller and larger subjects remained static and simply judged whether or not they could walk through an aperture without adjusting, aperture to shoulder width ratio was again consistent at 1.16 regardless of size. The results further support previous findings in that participants were able to make judgements based on intrinsic optical information relevant to action when walking through apertures (Warren and Whang, 1987).

In a study by van der Meer (1997), healthy adults, nursery school children, children with cerebral palsy, and infants with less than six weeks of independent walking experience walked and ran under barriers of varying heights. Results showed a body-scaled critical point for all but the infant subjects where participants felt the need to duck. Much like how a critical point was found by Warren (1984) where a stair became unclimbable, a constant ratio of barrier height to head height of 1.038 while walking, and 1.056 when running was found among adults, regardless of participant height. Nursery school children tended to have higher barrier to head height ratios than adults when both

walking and running. This suggested more cautious behaviour by the children to compensate for poorer motor control (van der Meer, 1997).

Coupled with evidence demonstrating changes in postural control as a function of age and fear of falling, it is possible that falls may be due to a perception-action uncoupling. If intrinsic capabilities, such as strength, cannot keep pace with extrinsic demands (environmental constraints), the result will be a constrained control system, where coordination between various motor and physiologic sub-systems no longer cooperate, and this in turn leads to a loss of balance. With declines in strength and reaction time, an environmental constraint that once afforded certain actions slowly becomes a barrier to those same actions. A simple example is that leg length remains constant as we age but strength does not. These declines in strength no longer afford the same actions as before, and so action is disrupted. A study by Laughton et al. (2003) found evidence of this type of constraint by comparing the EMG activity of four leg muscles of older and younger adults while tracking their postural sway. Older adults, both fallers and non-fallers, all showed greater muscle activation than the younger participants, which was correlated with increased postural sway. It was believed that in their efforts to stabilize, older adults activated more muscles to compensate for age-related strength declines. This in turn had the opposite effect on stability (Laughton et al., 2003). Dual-task paradigms intend to divide cognitive resources, but perhaps by focusing on affordances instead of cognitive strategies that interfere with automatic control, postural control can be facilitated. It may be that once a person allows him or herself to focus on the fear of losing balance or dwell on past experiences of a similar situation,

which involves a heavy cognitive load, automatic control becomes compromised exacerbates an already compromised system.

Whereas an otherwise healthy person would see stairs or a puddle as something to be traversed normally, an older adult with a visual impairment or a noticeable strength or mobility decline may act in a different way as they perceive these obstacles as being threats to their safety. These negative perceptions can lead to actions being taken to avoid the obstacle or to avoid situations entirely that pose a threat. Actions could also be taken that can exacerbate the poor balancing conditions unconsciously. It is this these types of reactions that can lead to injurious falls and perhaps even a fear of falling.

#### *Post-Fall Effects on Postural Control*

At its conception some 30 years ago, fear of falling was originally coined post-fall syndrome (Murphy & Isaacs, 1982; as cited by Legters, 2002), which described a situation where a person, typically older, who had sustained a potentially injurious fall would then live with the anxiety of falling again. Sufferers tended to adapt their lifestyles to the nagging fear of the possibility of falling again. Several definitions of fear of falling exist, with each one encompassing the overall idea of wariness of falls but from a more specific source. These can range from concerns about falling that limit the performance of daily activities, a person's confidence loss in his or her ability to balance, a general concept of low confidence in avoiding falls, to a general concern or worry about falling (Legters, 2002).

Several tools have been developed to assess the existence and degree to which a person has a fear of falling. Knowing that there are several factors involved, simply

asking a person if they are afraid of falling is hardly sufficient. Tinetti, Richman, and Powell (1990; as cited by Legters, 2002) developed one such tool called the Falls Efficacy Scale (FES) to examine older adults' self-confidence in avoiding falls during every day activities. There are 10 questions rated 1 to 10 for a total score of 0 to 100. An example question is "How confident are you that you can clean the house without falling?". The FES is typically used to assess older adults with low mobility or who are homebound, as it only measures indoor activity. Another assessment is the Fear of Falling Questionnaire (FFQ) developed by Dayhoff, Baird, Bennett, and Backer (1994; as cited by Bower et al., 2015), which takes into account the psychometrics involved in a fear falling instead of efficacy. Using Lazarus' (1991) (as cited by Bower et al. 2015) cognitive appraisal model of emotion, fear of falling is seen as a function of the emotion of fear and potential outcomes of harm and coping from a fall. As such, the FFQ presents statements and has test-takers rate their answers on a scale of 1 (not at all concerned) to 4 (very concerned). Example statements are: "If I fall, chances are I will be hurt in some way" and "I frequently limit my activities to prevent falling". The FFQ was revised by Bower et al. (2015) into the FFQ-R and shows reliability while being only six questions long.

The reasons for developing and maintaining a fear of falling are still widely debated, as there exist many possible contributing factors. Originally, it was believed that fear of falling was a result of having previously experienced a fall. However, additional research revealed other concerns. In a cross-sectional study by Brouwer et al. (2004), 25 adults aged 65 and older were gender and age-matched to 25 participants who met the researchers' criteria for having a fear of falling. Subjects had balance stability, walking

speed, and lower limb strength assessed, as well as completed several questionnaires. Major findings suggested that older adults with a fear of falling walked more slowly, had weaker lower limbs, and had poorer perceptions of physical health than their non-fearful counterparts, regardless of recent fall history. Muscle weakness was of particular concern, as it is a known predictor of falls and a factor in activity reduction (Brouwer et al., 2004). Unfortunately, with activity reduction comes increased muscle weakness, which can result in an even greater chance of falling. This is one of many examples of a physical factor contributing to a fear of falling.

Herman and Hausdorff (2005) examined 25 older adults with a more severe gait disorder and 28 age-matched controls in hopes of discovering why some older adults walk fearfully. Inclusion criteria for the gait disorder group was a self-reported walking impairment, unattributable to any disease or medical condition. Subjects had their mental condition, depression levels, and fear of falling assessed. Muscle strength, average gait speed and stride length, functional mobility, and balance were also assessed. There were three major findings related to fear of falling. Firstly, gait variability was higher among older adults with a fear of falling and higher-level gait variability than age-matched controls. Secondly, muscle strength and balance disturbances were not related to the level of gait variability, but instead, neuro-psychological factors such as fear of falling and depression. Finally, in subjects with higher-level gait disorders, fall history was not related to fear of falling or gait speed. This suggests that fear of falling can be highly psychological in nature, and that a history of falls is not necessary for it to be instilled (Herman & Hausdorff, 2005).

The typical scenario of risk factors leading to repeated falls was reinforced by Kabeshova et al. (2014) in their cross-sectional study of 1760 older, community-dwelling adults. A regression tree model was used to identify risk factors, and to specify which ones and which combinations led to the most repeated falls. Results showed a fear of falling being the strongest predictor of recurrent falls, regardless of the statistical analysis used. The second strongest predictor was “sad mood”. This is of little surprise, as gait speed tends to slow with increased sadness, which puts older adults at a higher risk of falling. The third strongest predictor was polypharmacy, which is a measure of health status. This is the classic scenario in which all factors cyclically affect one another, leading to increased depression, decreased health status, and a higher fear of or occurrence of falls (Kabeshova et al., 2014).

In an 11-year longitudinal study completed by by Clemson, Kendig, Mackenzie, and Browning (2015), risk factors for injurious falls and developing a fear of falling has also shed light on this phenomenon. Data from 1000 older adults was used and results showed an interesting pattern. Firstly, experiencing an injurious fall was not a predictor for developing a fear of falling. Likewise, having a fear of falling was not found to be a predictor for injurious falls. Secondly, the profile of a person who is likely to develop a fear of falling is markedly different than that of someone who will have an injurious fall, suggesting that these are two distinct issues that need to be dealt with accordingly. This also challenged the long-held notion of the typical fear of falling scenario as previously mentioned.

Kulmala et al. (2009) took a different approach to finding predictors in falls, and instead focused on vision and other sensory impairments. 428 women aged 63 to 76 had

their baseline visual acuity, hearing ability, and standing balance assessed. When a follow-up study was performed a year later, it was found that 47% of participants had experienced a fall, and that visual impairment when combined with either poor balance or poor hearing, increased the risk of falls. As well, when poor vision was combined with both poor balance and hearing, the risk increased further. This highlights the fact that there are sensory factors as well as physical and psychological factors associated with falling. Similarly, Crews and Campbell (2004) found that older adults with hearing loss showed diminished health; however, those with vision loss had greater declines in health, with the greatest decline associated with a combination of the two. These health impairments are typically associated with reduced activities and social participation, sadness, and falls. It is known that there is an existing link between older age and a decline in somatosensory systems necessary for balance, which leads to a heavier reliance on vision and attentional resources (cognition) for postural control. Unfortunately, decreases in visual effectiveness tend to progress as people age as well. With all of this in combination with the psychological factors associated with having a fear of falling, it is no surprise that the older population is at such great risk of experiencing an injurious fall.

### *Purpose*

The purpose of the study was to examine if older adults with a fear of falling were affected differently by different levels of cognitive loads and challenging environments, and if perceived environmental “threats” lead to greater investment of cognitive effort in at-risk for falls older adults compared to age-matched, healthy controls.



### *Hypotheses*

Hypothesis 1 - Postural Sway: Postural sway will increase (poorer) as a function of cognitive load, and the Fear of Falling group will have greater postural sway than the control group.

Hypothesis 2 - Pupil Size and Heart Rate: Arousal levels will increase as a function of cognitive load, and the Fear of Falling group will show larger increases than the control group.

Hypothesis 3 - Threat Ratings: the Fear of Falling group will perceive more environmental “threats” than the Control group, and there will be a relationship between perceived environmental threat and physiological indices.

## CHAPTER 2

### METHODS

#### *Participants*

21 healthy male and female participants were recruited (14 female, 7 male) with a mean age of 67.7 years. Participants were free of any acute or chronic lower limb injuries and had normal to corrected normal vision. Participants were separated into the control group or the Fear of Falling (FoF) group based on their responses to a pre-test questionnaire. The control group had 10 females and 7 males with a mean age of 68.35 years, while the FoF group had four females with a mean age of 67 years.

### *Instruments*

A Google Nexus 5 phone camera was used to take the pictures of scenes for participants to inspect (see Appendix 1,2,3). All images and information for other conditions were shown on a Dynex 42" flat screen television, located approximately a meter in front of the participants. A head mounted ASL Eye-Trac 6 system was worn by all participants to record eye movements, visual focus, and pupil dilations as they looked at the screen. Participants were asked to keep their heads as stationary as possible during the calibration process throughout all trials. The eye monitor was connected to the Eye-Trac 6 .NET User Interface program, which measured where the eye was focused on a computer screen. The measures for the eye tracker were pupil dilation and fixation duration. Pupil dilation is typically associated with arousal and fixation duration indicated areas of interest where participants were attending to. Video Play Control software allowed the computer to sync the beginning of eye data collection with the video presentation on the television.

An AMTI force platform with an MSA-6 Mini Amp was used to record participants' postural sway across the trials with the use of a Generic DAQ software. A custom setup was made within the Generic DAQ software so that the activation of the Video Play Control software sent a frequency in a separate channel across software to show the exact time in which the videos were played and eye data collection began, thus allowing for perfect synchronization. Postural sway data was recorded as forces and moments in the x, y, and z directions. Duct tape was used to mark the participants' heel positions on the force platform should they have needed to step off for any reason, while a measuring tape was used to measure base of support width.

A *ProComp Infiniti*<sup>TM</sup> Biofeedback (Thought Technology Ltd, “TT”) Encoder was used to monitor participants' physiological arousal levels across all trials on a separate computer. The measures were skin temperature in degrees Celsius, skin conductance in micro-Siemens, heart rate (HR) in beats per minute, and blood volume pulse. Only heart rate was used in the analyses based on the results of a pilot study. Alcohol swabs were used to sanitize the equipment between participants.

The Stroop Colour Word Test, which displays the names of colours while the letters themselves are of a different colour, was used to induce anxious arousal and also serve as the “heavy cognitive load” condition. Participants were required to speak aloud the colour of the word and not the colour the word actually spelled out.

The pretest questionnaire was a combination of the Fear of Falling Questionnaire Revised (FFQ-R) and the Short Falls Efficacy Scale I (Short FES-I). The FFQR has been shown to reliably identify the existence of a fear of falling (Bower et al., 2015), whereas the Short FES-I as been shown to identify a more real-world fear of falling involving social and activities of daily living (Kempen, et al., 2007; Delbaere et al., 2010) (see Appendix 4). Participants that scored above 26 out of a possible 52 were put into the FoF group (the "heights make me uncomfortable" question was not included in the scoring as it was a supplementary question and not part of the FFQ-R or Short FES-I).

### *Procedures*

Participants were notified of the study via word of mouth and flyers in a local organization called Life After 50. Once an agreed upon date and time had been scheduled via email, participants were invited to come in to the HK Motor Control Laboratory.

Participants were asked to wear socks, as all balance trials would be done in stocking feet. Upon arriving for data collection, participants were invited to sit at a table where the consent form and questionnaire were completed. Participants were given ample time to read the forms and ask any questions to help clarify what would be expected of them. Once finished the falls questionnaire and consent form, they were asked to indicate their age, sex, whether or not they were comfortable in the temperature of the room, and what medications they were on.

Participants were first asked to remove their shoes for the purposes of standardization. The eye tracker was then secured onto the participants' heads. Using an alcohol swab, the researcher sanitized and affixed all biofeedback sensors to the participants' left hands and confirmed that all were reading properly. Participants were then asked to step on to the force platform and find a comfortable foot position. Tape was placed at the heel to assure that foot position remained in a fairly consistent location should any participant have requested a rest between conditions that required them to step off of the force platform. Height and base of support width were then measured from the inner most part of the heels and noted. Next, the eye tracker was calibrated.

The study followed the sequence of baseline, light cognitive load (LCL), environmental threat (ET), and the anxious arousal (Stroop) conditions for testing. The participants were informed what condition of the four was being conducted, as well as were read aloud a set of instructions for each condition. There were three trials of data recorded for the baseline, LCL, and Stroop condition, and five trials recorded in the EV condition. In total, the time required of each participant was approximately 40 minutes.

At the start of every trial in each condition, biofeedback, eye-tracking, and force platform data collection was synced to start and finish at the same time. Condition 1 (Baseline) had the participants listen to instructions stating: "This is the baseline condition. You're being asked to stand silently as still as possible and stare at the X in the middle of the screen for 30 seconds. I will have you do this three separate times with a small break in between each. I will count you down when it is time to begin". Participants will then be asked if they understood or needed clarification before beginning. The researcher counted down from three and then began data collection. At the end of the first and second trials, participants were given 30 seconds to relax before the next trial began with a countdown. The researcher asked participants if they would like to sit down and rest between each condition.

Condition 2 (LCL) had participants listen to instructions stating: "This is the second condition. You're being asked to stand as still as possible and read out loud the 10 words that will come up in the middle of the screen for three seconds each. I will have you do this three separate times with a small break in between. I will count you down when it is time to begin". Participants were again asked if they understood or needed clarification before beginning and the same between-trial procedures as the previous condition were done.

Condition 3 (ET) consisted of five, 20 second trials in which a static image of an environment was presented (see Appendix 1,2,3). Before each image, a white screen with moving X was shown to assure that the eye tracker was tracking the whole scene and to standardize starting eye position. The movement order was two seconds each in the top left corner, top right corner, bottom right corner, bottom left corner, and then centre.

They were told: "I'm going to show you five pictures on the screen for 20 seconds each. Before each picture comes on screen, an X will move around the screen from the top left corner to the top right corner, then the bottom right corner, bottom left corner, and then the centre. Please follow the X and then inspect the scene for the duration of the trial however you please". Between each ET trial, participants had 30 seconds to rest. Participants were again asked if they needed a break when all trials were finished before moving on to the final condition.

Condition 4 (Stroop) was the anxious arousal condition and consisted of three trials of increasing difficulty (decreasing time length) where participants performed the Stroop colour word test. All trials began with a 10 second X in the middle of the screen. Trial one was 30 seconds, trial two was 24 seconds, and trial three was 18 seconds. Participants were told that they "must speak aloud the colour of the word and not the colour the word actually spells out as fast and as accurately as possible". The researcher also encouraged participants to go as fast as possible. Once the trials of condition 3 were completed, data collection was completed.

### *Data Analysis*

All LCL trials had the first three seconds of data removed from the force plate, eye tracking, and biofeedback data. All picture trials and Stroop trials had the first 10 seconds removed for all data types. These data were removed as they were simply an X on a blank screen to standardize participants' starting eye position as well as to provide time in between trials to return to a more normal state should someone have become physiologically or cognitively aroused. Force plate data was converted to a Mean Moving

Window (MMW) by first calculating the resultant sway by taking the square root of  $Mx^2 + My^2$ . MMW was calculated by finding the mean of the SD of every 100 data points of resultant sway.

Three separate 2 (Group) X 3 (Cognitive Load Condition) mixed factorial ANOVAs with repeated measures were run for HR, Pupil size, and MMW. Three more 2 (Group) X 3 (Environment Type) mixed factorial ANOVAs with repeated measures were run for the same three variables. Two ET trials were omitted for providing nothing notably different than the chosen mundane trial, as all three presented a relatively plain background with one obstacle on the ground in relatively close proximity to the viewer. Finally, correlation matrices were done comparing the three levels of cognitive load conditions (Baseline, LCL, and Stroop) with the three corresponding levels of Environmental Threat trials (mundane, threatening, busy).

## CHAPTER 3

### RESULTS

#### *Heart Rate*

Analysis of HR in the cognitive load conditions yielded a significant main effect for condition  $F(2,18) = 29.817, p = .000 < .05, \eta^2 = .768$ . Bonferroni post-hoc analysis revealed that all conditions were significantly different from each other at  $p = .000 < .05$  (Figure 1), suggesting increased physiological response as a function of task difficulty. There was no significant interaction between group and condition  $F(2,18) = .521, p = .603 > .05$ . The analysis of HR data under the three environment conditions found no significant main effects  $F(2,18) = 1.513, p = .247 > .05$  or interaction,  $F(2,18) = .299, p =$

.745 > .05 (Figure 1). The correlation analysis for HR revealed significant correlations of .742 between Baseline and Mundane Environment, .681 between LCL and Busy Environment, and .618 between HCL and Threatening Environment for the control group (Table 1). For the FoF group, no significant correlations were found for the same three pairs of conditions.

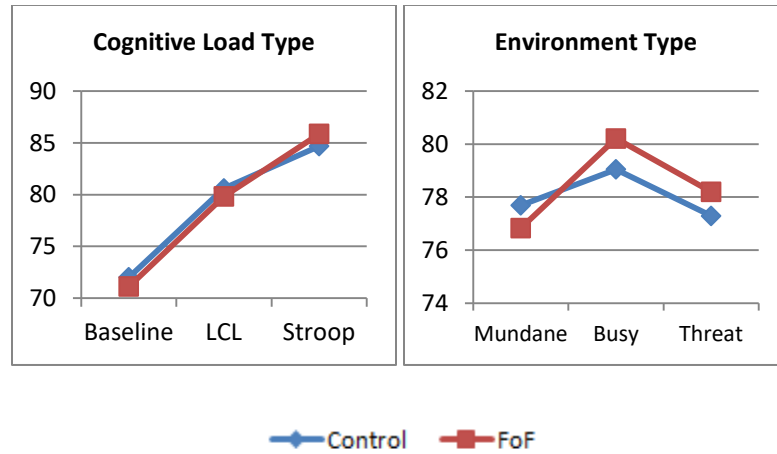


Fig.1. HR \* Condition and HR \* Environment Type

	Heart Rate			Pupil Size			Mean Moving Window		
	Base/Mund	LCL/Busy	Str/Threat	Base/Mund	LCL/Busy	Str/Threat	Base/Mund	LCL/Busy	Str/Threat
Control	0.742*	0.681*	0.618*	0.827*	0.778*	0.981*	0.080	0.874*	0.436
FoF	0.935	0.944	0.872	0.961*	0.966*	0.995*	0.847	0.779	0.829

Table 1. Correlation matrices for HR, Pupil Size, and MMW for like pairs of cognitive load and ET conditions



## Pupil Size

Analysis of pupil data in the cognitive load conditions (Figure 2) revealed a significant main effect of condition  $F(2,18) = 4.743, p = .022 < .05, \eta^2 = .345$ . The Bonferroni post-hoc found only a significant difference between the Light Cognitive Load and the Stroop conditions,  $p = .025 < .05$ . There was no interaction between group and condition,  $F(2,18) = .599, p = .560 > .05$ . Pupil analysis for the three environmental threat conditions revealed no significant main effects  $F(2,18) = 2.133, p = .147 > .05$  and no significant interaction  $F(2,18) = .394, p = .680 > .05$  (Figure 2). Next, the correlation matrix for Pupil Size (Table 1) showed significant correlations of .827 between Baseline and Mundane Environment, .778 between LCL and Busy Environment, and .981 between HCL and Threatening Environment for the control group. For the FoF group, significant correlations of .961, .996, and .995 were found for the same three pairs, respectively.

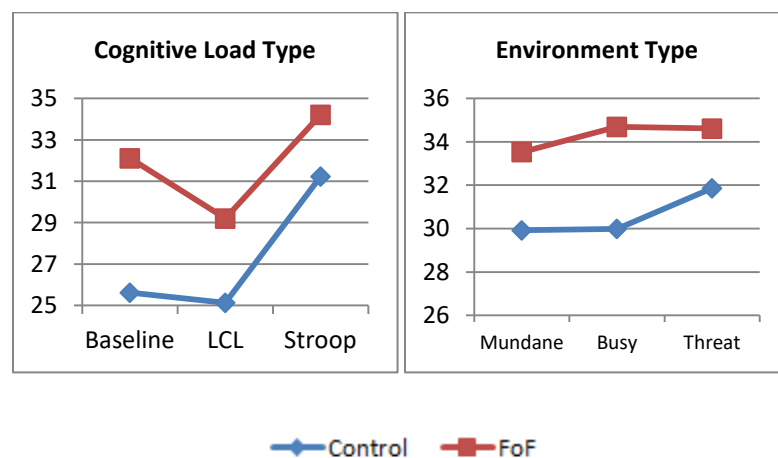


Fig. 2. Pupil Size \* Condition and Pupil Size \* Environment Type

### Mean Moving Window

For MMW in the cognitive load conditions, there was a significant main effect of condition,  $F(2,18) = 10.918, p = .001 < .05, \eta^2 = .548$  (Figure 3). The Bonferroni post-hoc revealed a significant difference between the baseline and Stroop conditions at  $p = .000 < .05$ , as well as the LCL and Stroop conditions at  $p = .004 < .05$ . There was no significant interaction effect of Condition X Group at  $F(2,18) = .467, p = .634 > .05$ . MMW in the three environmental threat conditions found no significant main effects  $F(2,18) = .842, p = .447 > .05$  or interaction effects at  $F(2,18) = 1.350, p = .284 > .05$  (Figure 3). Finally, the correlation matrix for MMW (Table 1) showed only one significant correlation of .874 between LCL and Busy Environment, for the control group. No significant correlations were found for the FoF group.

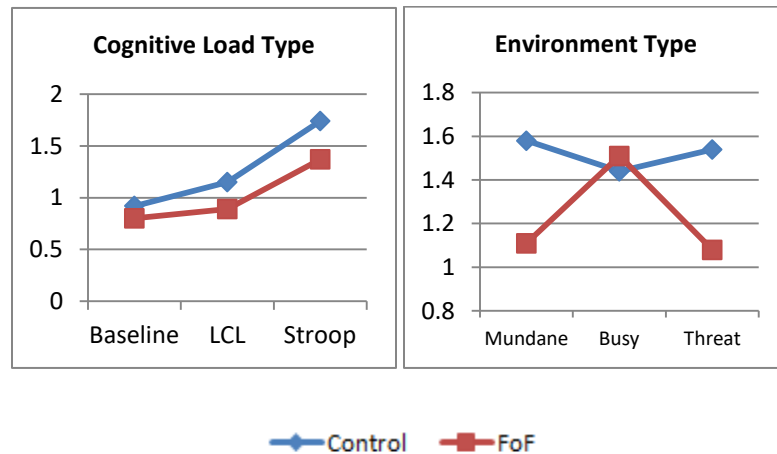


Fig. 3. MMW \* Condition and MMW \* Environment Type

		Control		FoF	
		M	SD	M	SD
HR	Base	72.02	11.78	71.13	14
	LCL	80.6	12.04	79.83	8.86
	Stroop	84.69	11.77	85.87	10.86
Pupil Size	Base	25.62	10.77	32.11	2.94
	LCL	25.13	11.5	29.2	8.31
	Stroop	31.23	9.53	34.21	5.24
MMW	Base	0.92	0.32	0.8	0.33
	LCL	1.15	0.5	0.89	0.3
	Stroop	1.74	0.74	1.37	0.5
HR	Mundane	77.69	12.13	76.83	9.25
	Busy	79.05	11.4	80.21	8.13
	Threat	77.29	11.99	78.2	11.79
Pupil Size	Mundane	29.92	11.6	33.53	6.97
	Busy	29.99	13.62	34.69	6.2
	Threat	31.86	12.3	34.61	7.3
MMW	Mundane	1.58	1.29	1.11	0.41
	Busy	1.44	0.82	1.51	0.77
	Threat	1.54	1.25	1.08	0.47

Table 2. Means and Standard Deviations for HR, Pupil Size, and MMW for Control and FoF groups for all conditions

## CHAPTER 4

### DISCUSSION

#### *Cognitive Load Conditions*

It was expected that different cognitive loads would affect both groups similarly, but that the FoF group would have a larger MMW than the control group. The larger MMW for the FoF group would suggest a greater amount of postural sway and less postural stability, especially when the task required a heavier cognitive load. These

factors could account for uncertainty in stability or a fear of falling. Similarly, HR and Pupil Size were both expected to increase in both groups with increasing cognitive loads, with HR being greater in the FoF group than the Control group. These increases would suggest increased cognitive and physiological arousal, and a further physiological arousal in the FoF group that would be akin to a stress or anxiety response.

Analyses revealed that different cognitive loads affected both groups similarly, especially for HR, which was almost identical (Figure 1). These findings suggest that different cognitive loads did not lead to higher physiological responses in the participants who scored high enough to qualify as having a fear of falling, and that perhaps “fear” or “anxiety” are not appropriate descriptors for people with concerns about future falls. Instead, both groups appear to have used similar strategies as the cognitive load increased. The LCL condition was not overly cognitively demanding and all participants were able to complete the task successfully without it negatively affecting their stability. However, the heavy cognitive load presented by the Stroop colour-word test appears to have required much more of their available cognitive resources to the point of even increasing postural sway.

The MMW findings in the FoF group are contrary to what was expected based on previous studies examining the effect of cognitive load on postural sway. Although not statistically significant, the results showed a trend that MMW in the FoF group was actually slightly lower than the Control group. The finding of no difference between groups could be due to physical overcompensation (Laughton et al., 2003) in the FoF group, where the participants reduced sway variability in an effort to stabilize balance. In fact, according to the “constrained action hypothesis” proposed by Wulf, McNevin, and

Shea (2001), reduced postural sway may be evidence that participants in this study compensated for the added cognitive load by freezing the degrees of freedom associated with maintaining their posture; thereby impeding optimal control. This is also consistent with the results of Balasubramaniam et al. (2000), who found that a minimum amount of sway variability is necessary for flexibility in maintaining balance, and that reducing degrees of freedom could be a detrimental by increasing postural sway in a different direction or compromising the ability to make adjustments.

There were no significant differences found between the control group and the FoF group in any of the cognitive load conditions. Although there appear to be some small group differences when analyzing the results (Figure 1, Figure 2, Figure 3), none were detected. This was likely due to the small sample size of the FoF group, which reduced power. Despite the statistical non-significance, the direction of the results were encouraging. Mean pupil size appeared to be larger in the FoF group in all three cognitive load conditions, which, with more power, would have lent support to the previous suggestion that those participants were investing more cognitive resources than those in the Control group. This trend further supports the lack of difference found between groups for HR, in that it could be the use of cognitive resources was different between groups but not the physiological responses.

#### *Environmental Threat Conditions*

The environmental threat condition was where the biggest differences were expected to be found, due to the potential of differing perceptions between older, healthy individuals, and older, healthy individuals with a fear of falling. This condition was

designed to have perceptions of an environment directly affect arousal measures, and in turn, postural sway. However, the analyses found no significant effects of environment type on either group and no significant differences between groups. Once again, there appear to be small group differences (Figure 1, Figure 2, Figure 3), but nothing of statistical significance. Insufficient power from unequal groups and too small of a sample size are, again, the likely explanations for the failure to detect group differences. Additionally, the eye-tracking equipment was unable to monitor where on each picture subjects were looking with acceptable accuracy, and so it was not possible to positively identify areas of perceived threat or general interest. Expectations were that participants in the FoF group would fixate longer and more often on potential tripping hazards/ threats or handrails than those in the control group, and that changes in arousal would be reflected in their postural sway, HR, and pupil size.

The direction of the MMW trend (Figure 3) points to possible group differences in postural sway based on environment type. The control group remained relatively the same, whereas the FoF group showed an increase in the Busy environment, possibly due to cognitive load as they were trying to attend to many environmental factors, and a decrease or freezing response in the Threatening environment, possibly due to the impending threat of looming stairs. This trend can also be related to the pilot study wherein the younger adults undergoing the same procedures showed little to no change in MMW across levels of ET, suggesting they had a similar strategy as the control group in this study. Both the younger and older control group adults swayed freely and without significant physiological or cognitive arousal, which

would allow for flexibility in postural adjustments in the face of a challenging or threatening environment.

### *Correlations*

The correlation matrices show significant moderate to strong positive correlations for HR, Pupil Size, and MMW in the control group between the paired environment and cognitive loads in all pairs except for MMW in Baseline/Mundane and Stroop/Threat. This could be indicative that the threat level or intensity of the selected environments presented a reasonably close cognitive load to their matched condition pairs or that busier or potentially more dangerous environments were perceived to require more attention or present more challenges. Much like the previous analyses, there appear to be differences between groups, as the FoF group had consistently stronger correlations than the Control group in all pairs except for the LCL/Busy pair; however, the small group size did not allow what are obviously high correlation values to be statistically significant. Only the Pupil Size correlations are significant and highly correlated, suggesting a very similar amount of cognitive arousal between matched condition pairs.

The strong correlations from both groups suggest that similar strategies were adopted under the different conditions. The lowest cognitive load (Baseline) was correlated with the Mundane environment, the LCL was correlated with the busy environment, and the highest cognitive load (Stroop) was correlated with the Threatening environment. This suggests that the amount and type of affordances in the environment are comparable to different types of cognitive loads and this would explain the resulting changes in physiological responses, cognitive responses, and changes in postural sway.

Additionally, from a direct perception perspective, the fact that participants from both groups perceived the threatening environment as a heavy cognitive load in a similar way suggests that those in the FoF group's perceptions have not been compromised by past falls or a fear of future falls. The MMW graph (Figure 3) shows different postural sway for both groups in the Mundane and Busy environments. However, the trend, although statistically insignificant, points to the FoF group showing decreasing postural sway during the threatening environmental trial whereas the control group showed very little change throughout all trials, suggesting that they were free to sway comfortably. It is possible that the perception-action link in the FoF group participants has been compromised by a fear of falling, in that their ability to perceive environmental threats has become dissociated from their ability respond appropriately with postural adjustments. This is supported by the findings that FoF participants had lower postural sway under the threat condition, which suggested a freezing of the degrees of freedom. The HR results from the ET condition (Figure 1) further support this idea in that both groups appear to have recognized the threat of looming stairs with increases in HR, but only those in the FoF group showed visible changes in postural sway.

### *Limitations*

The biggest limitation was the small sample size and uneven groups that did not provide enough power to detect group differences. Along with this limitation, the age cut-off may have been too low to truly represent older adults. However, it was necessary based on time constraints and facilitation of recruitment. Another limitation was the outdated and inaccurate equipment that lead to unusable eye tracking data. The moving X



prior to ET trials was a failsafe to see if the data would be viable within the first 10 seconds. Only eight of 21 participants had useable eye data which were not used in the analyses. However, pupil size was still viable as it registered zeros for when the lock on the pupil was lost, much like when participants would blink.

A possible explanation for the previous limitation and a limitation in itself was height differences among participants and non-adjustable TV height due to the eye tracker having been calibrated for its specific location. Since heights ranged from 152 to 185 cm, the participants on the highest and lowest ends had visible errors in eye tracking from changes in eyelid location due to looking up or down. Even though the starting point for each ET trial was standardized on the screen, individual differences led to very different starting eye positions.

One potentially strong factor to be addressed was that the FoF group was female only. The biggest difference one would expect between sexes would be HR; however, there were no significant differences between groups. An interesting finding was that zero of seven males scored high enough to qualify as having a fear of falling, whereas four of 14 females scored high enough. As previously mentioned, females tend to be injured more by falling but males have a higher death rate from falling (Parachute, 2015; CDC, 2009). It is possible that more females will have the opportunity to develop a fear of falling due to a longer lifespan and lower death rates from falling.

Another limitation was the vagueness of the instructions during the LCL and ET conditions. Multiple participants said they were looking for things and trying to memorize details instead of putting themselves in the environment and imagining having to navigate the scene during the ET condition. Participants also told the researcher that

they thought they had to memorize the words on screen. In other words, around half of participants were expecting some type of deception or memory test despite having read the letter of information. If replicating this study, modifying the instructions to explicitly tell participants to imagine themselves having to navigate the environment on the screen as opposed to just looking at it would be a very good practice. In trying not to influence participants in any way, the less direct instructions may have taken away from having them view the environment as something to be navigated instead of just a picture. Additionally, telling participants that they simply have to read the words on screen and not worry about memorizing anything may also be beneficial.

Future directions for this study would benefit from the use of a first person video instead of a static scene to better immerse participants into the environment, along with better eye-tracking equipment and adjustable television height that would allow for much stronger relationships to be observed between what is truly being attended to in the environment. Cues could be planted in the environment, such as objects of different colours, and participants could be required to count them. This would ensure that they do not glaze over the environment while focusing on a cognitive task. It would also be interesting to add a cue that required participants to lift one foot off the ground and analyze changes in postural sway and reaction time to see how groups might differ. It is also encouraged to use a more challenging LCL task such as basic arithmetic or backwards counting by 3s to keep participants more fully engaged throughout the entirety of the trial. Finally, the unexpected finding of sex differences and frequency of people who score high on the FES and FFQ scales would do well to be further investigated with a much larger sample size. There were participants who had answered yes to falling in the

past year in both groups in the this, as well as some that answered no in both groups. The fallers in the control group may have a different outlook on falls wherein they see falls as a something that can and will happen, and deal with it as such, as opposed to someone who becomes anxious or fearful and alters their behaviours as a result.

### *Conclusion*

The aim of this study was to find differences in perception and cognitive strategies between healthy older adults and healthy older adults with a fear of falling. It was shown that older adults, regardless of concerns of falling, tend to show increases in physiological and cognitive arousal with heavier cognitive loads, and increased postural sway as a result of these changes. These results support previous information-processing model dual-task paradigm studies on cognitive load and postural sway. Due to the sample size, no statistically significant differences were found between groups, however the trend that may point to the FoF group having reacted differently to the control group in the Environmental Threat trials is still an encouraging finding.

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APPENDICES

*Appendix 1: Mundane Environment*



*Appendix 2: Busy Environment*



*Appendix 3: Threatening Environment*



*Appendix 4: Pre-test Questionnaire*

Questions	Strongly disagree agree				Strongly agree
1. If I fall, chances are I will be hurt in some way.	1	2	3	4	
2. I am afraid of falling again.	1	2	3	4	
3. If I fall, my life would change greatly.	1	2	3	4	
4. The thought of falling really frightens me.	1	2	3	4	
5. I will probably fall if I get dizzy or trip.	1	2	3	4	
6. One of my worst fears is that I will fall.	1	2	3	4	
7. Heights make me uncomfortable.					
For each of the following activities, please circle the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.					
	Not at all concerned concerned				Very concerned
1. Getting dressed or undressed	1	2	3	4	
2. Taking a bath or shower	1	2	3	4	
3. Getting in or out of a chair	1	2	3	4	
4. Going up or down stairs	1	2	3	4	
5. Reaching for something above your head or on the ground	1	2	3	4	
6. Walking up or down a slope	1	2	3	4	
7. Going out to a social event (e.g. religious service, family gathering, or club meeting)	1	2	3	4	
Please circle yes or no.					
I have fallen at least once in the past year.	YES	NO			

## VITA AUCTORIS

NAME: Shawn R. Reaume

PLACE OF BIRTH: Windsor, ON

YEAR OF BIRTH: 1990

EDUCATION: St. Thomas of Villnova High School, LaSalle, ON,  
2008

University of Windsor, B.H.K., Windsor, ON, 2014