

**Attentional Contributions to Postural Control are Altered in Older Adults
who Fear Falling**

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Dedication

In loving memory of my dad Terry White. Thank you for teaching me that I can do anything that I put my mind to.

Abstract

The purpose of this thesis was to compare the contributions of attentional resources relevant to postural control between fall-fearful and non-fearful older adults. Levels of postural challenge and instructions of task prioritization were manipulated to obtain this goal. Results indicated that fall-fearful subjects demonstrated a reorganization of attentional resources when challenge to upright standing was imposed. Additionally, only non-fearful subjects demonstrated flexibility in the prioritization of the cognitive task. However both fall-fearful and non-fearful subjects demonstrated flexibility in the prioritization of the postural task. Findings suggested that fall-fearful older adults reorganize the allocation of attentional resources differently than non-fearful counterparts, potentially placing them at greater risk for falling as their awareness of the external environment and threats to balance may be compromised.

Acknowledgments

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Chapter 1: General Introduction

Every year one third of the senior population over the age of 65 will experience a fall (Sattin, 1992). The probability of experiencing a fall increases to between 40-80% for those over the age of 80 years (Hess & Woollacott, 2005; Tinetti, Speechley, & Ginter, 1988). Injuries from a fall, such as soft tissue injuries or broken bones (Tinetti, et al., 1988) can lead to diminished physical function (Campbell, et al., 1990; Petrella, Payne, Myers, Overend, & Chesworth, 2000) and a consequential loss of independence and quality of life (Powell & Myers, 1995; Zeeuwe, et al., 2006). As well as the possibility of injurious consequences, a fall episode can also create an imposing concern about the possibility of experiencing a future fall. This concern is recognized among clinicians and practitioners and is referred to as fear of falling (FOF). FOF is gaining recognition as a serious health problem in the senior population, ranking highest amongst reported fears of older adults by surpassing common fears in this age cohort such as being victimized by crime or suffering from financial problems (Howland, et al., 1993).

One consequence associated with fear of falling is a reduced participation in activities of daily living (ADLs) (Maki, Holliday, & Topper, 1991). Activity restriction can lead to the loss of muscular strength and endurance critical to the performance of daily tasks (Cumming, Salkeld, Thomas, & Szonyi, 2000). The ultimate consequence of activity restriction is increased fall risk (Myers, et al., 1996).

Early research suggested that FOF was caused by the occurrence of a fall episode and was consequently termed 'post fall syndrome' (Murphy & Isaacs, 1982). Of those who experience a fall, up to 92% may develop a fear of falling (Aoyagi, et al.,

1998; Howland, et al., 1993; Legters, 2002). Interestingly, research has also revealed that a significant number of non-fallers also express a concern about falling (Legters, 2002; Maki, et al., 1991; Myers, et al., 1996; Tinetti, Mendes de Leon, Doucette, & Baker, 1994). This finding has led to a refinement of the term “fear of falling” to include both fallers and non-fallers (Legters, 2002; Maki, et al., 1991).

There is some controversy over the vocabulary used to describe and define fear of falling (Jorstad, Hauer, Becker, & Lamb, 2005). Researchers often refrain from using such terms as “fear”, “anxiety” or “afraid” as these words may be interpreted as too ‘severe’ by participants in relation to their feelings towards falling. Participants may not express an actual “fear” towards falling, but may still describe concerns about the possibility of falling (Jorstad, et al., 2005; Li, et al., 2002; Maki, et al., 1991). Consequently, alternative descriptions like “worry”, “concern” or “troubled” have been used as substitutes for “fear” in different studies in an effort to attract more participants with differing intensities of fear (Jorstad, et al., 2005; Lachman, et al., 1998).

A fundamental term within the FOF construct is “fall-related self-efficacy” (FSE). FSE was adapted from Bandura’s theory of self-efficacy and defined as one’s perception of his or her ability to perform particular activities (Bandura, 1982). In relation to falling, FSE is defined as “one’s confidence in his or her capabilities to perform daily activities without falling (Tinetti, Richman, & Powell, 1990, p. 36).” Early research (Tinetti & Powell, 1993) used terms of FOF and FSE interchangeably, but FSE has since become aligned with self efficacy research and has mounted an independent literature base (Legters, 2002; Li, et al., 2002; Tinetti & Powell, 1993). FSE is useful in the understanding of the development of FOF (Tinetti & Powell, 1993). For example, Li and

colleagues (2002) investigated the relationship between FSE, FOF and physical function, and confirmed that fear of falling was significantly related to FSE, but not to physical function. FSE however was associated with both FOF and physical function. This relationship indicates that FSE may act as a mediator between FOF and physical function. The relationship between FOF, FSE and physical function is illustrated in Figure 1.1.

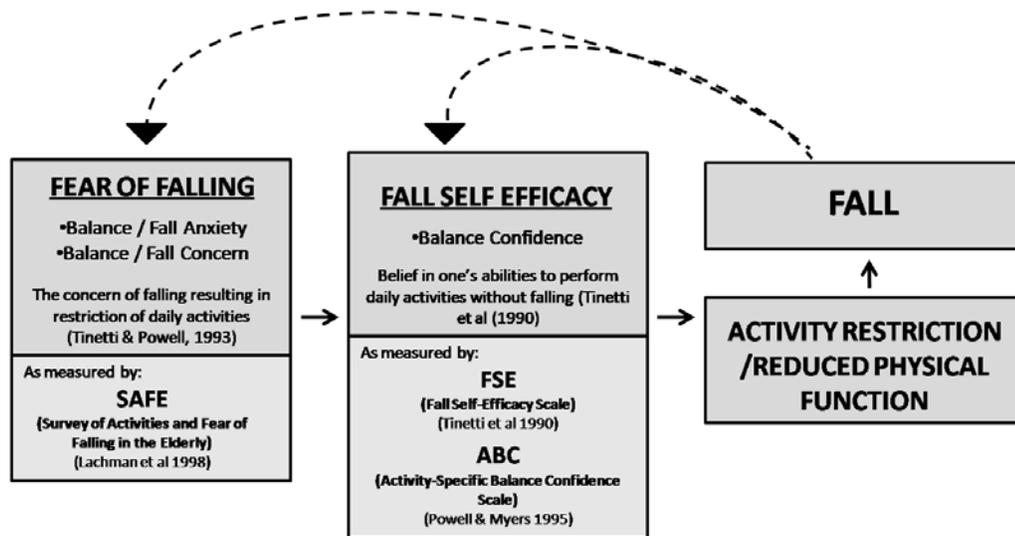


Figure 1.1 The relationship between fear of falling (FOF), fall self-efficacy (FSE) and physical function leading to potential fall risk. FOF leads to reduced FSE which acts as a mediator between FOF and physical function leading to activity restriction and the increased risk of a fall. As implied by the dashed line, a fall could, but does not necessarily lead to increased FOF.

FSE is relevant to research studies that examine the development of fear of falling. The work presented in this thesis involves people who have self-identified an existing fear of falling. Therefore, for this thesis, fear of falling is operationally defined according to the definition provided by Tinetti & Powell (1993) as:

The concern of falling that may result in the restriction of daily activities.

The term “fear” has been closely linked to “anxiety” in much of the literature, making it necessary to distinguish between the two terms. Epstein (1972) described fear in relation to the action of avoiding a threat. If this action is blocked or unattainable (i.e. a fall fearful individual is required to walk down icy steps to get to his or her car), then fear may transform into anxiety. Accordingly, anxiety is described as an unresolved fear, or a temporary state of arousal as a consequence to a perceived threat (Epstein, 1972). Within the context of fear of falling, Tinetti and Powell (1993) define FOF as a continuous awareness about falling leading to the avoidance of daily activities. However, the research setting inhibits the avoidance of vulnerable feelings about losing one’s balance, thus potentially eliciting responses of anxiety.

1.1 Fear of Falling Literature

1.1.1 Measurement tools for identifying and assessing fear of falling.

Originally a dichotomous “yes” or “no” answer was used to answer the question “are you afraid of falling?” (Maki, et al., 1991; Tinetti & Powell, 1993). This measure was later criticized due to an inability to evaluate the severity of fear related to falling (Howland, et al., 1993). Consequently, the number of possible responses was later expanded to a four point rating scale; “not at all afraid”, “slightly afraid”, “somewhat afraid”, and “very afraid” to provide insight into the extent of FOF that different individuals experienced (Lawrence, et al., 1998; McAuley, Mihalko, & Rosengren, 1997). This approach led to the development of a number of questionnaires to measure levels of balance confidence. For example, the Falls Efficacy Scale (FES; Tinetti et al., 1990) examines self-confidence

in the ability to avoid falling while performing daily activities. Although considered to be a valid measurement of falls self-efficacy, one drawback to the FES is that it is restricted to activities around the home and is therefore most suitable for lower functioning, homebound individuals (Legters, 2002; Tinetti, et al., 1990). The Activities-Specific Balance Confidence Scale (ABC; Powel & Myers, 1995) assesses balance confidence among independent and ambulatory older adults. Like the FES, the ABC requires subjects to rate balance confidence during daily activities. However, the tasks used in the ABC are more challenging than those of the FES and therefore more suitable for a higher functioning population (Legters, 2002; Powell & Myers, 1995). The Survey of Activities and Fear of Falling in the Elderly (SAFFE; Lachman, et al., 1998) was developed to examine the relationship between FOF and the possibility of activity curtailment. The SAFFE differs from the FSE and ABC by differentiating those who restrict activity levels due to FOF from those who do not (Lachman, et al., 1998). These scales (described in Table 1.1) can be useful measures of FOF, provided they are applied to the appropriate group of individuals (Legters, 2002). The advantage of the FSE and ABC is that they are better at predicting future falls, and are simple and time efficient to complete in the research setting. Alternatively, the SAFFE is a better predictor of activity avoidance, but requires assistance and explanation from the researcher (Hadjistavropoulos, et al., 2007; Jorstad, et al., 2005).

Table 1.1 Popular Fear of Falling Measurement Tools.

| Instrument | Population | Construct | Reliability | Validity |
|---|---|-----------------------|------------------------|-----------------|
| FES (Fall Efficacy Scale) | <ul style="list-style-type: none"> • Community • Patients | Fall-Related Efficacy | Adequate-Good (.71) | Adequate |
| ABC (Activity Specific Balance Confidence Scale) | <ul style="list-style-type: none"> • Community • Patients | Balance Confidence | Good (.92) | Adequate |
| SAFFE (Survey of Activities and Fear of Falling in the Elderly) | <ul style="list-style-type: none"> • Community | Fear of Falling | Weak (.49-.77) | Adequate |

(Jorstad et al., 2005; Lachman et al., 1998; Powell & Myers, 1995; Tinetti & Powell, 1993)

1.1.2 Risk factors associated with developing fear of falling. The risk of developing fear of falling is associated with a number of factors. These factors may include increasing age, female gender, the use of medications, poor health status, the use of a walking aid, poor balance, and a history of falls (Arfken, Lach, Birge, & Miller, 1994; Hatch, Gill-Body, & Portney, 2003; Howland, et al., 1993; Murphy, Williams, & Gill, 2002; Vellas, Wayne, Romero, Baumgartner, & Garry, 1997). Regardless of the underlying reason for the presence of FOF, a consistent finding is that FOF increases the risk of falling (Delbaere, Crombez, Vanderstraeten, Willems, & Cambier, 2004; Hadjistavropoulos, et al., 2007; Howland, et al., 1998; Howland, et al., 1993; Lachman, et al., 1998; Murphy, et al., 2002; Vellas, et al., 1997). One theory to explain how FOF increases fall risk is that the cautious performance of ADLs may be beneficial to fall prevention, but excessive anxiety towards falling may interfere with focusing the current task and consequently heighten fall risk (Hadjistavropoulos, et al., 2007; Howland, et al., 1998; Lachman, et al., 1998; S. L. Murphy, et al., 2002).

Findings are equivocal regarding the relationship between falling and fear of falling. Hatch and colleagues (2003) found that fall history did not influence FOF, however balance ability and functional mobility were significantly associated with falls. In contrast, other studies (Hadjistavropoulos, et al., 2007; Howland, et al., 1993; Vellas, et al., 1997) have reported falls to be significantly associated with fear of falling. Friedman and colleagues (2002) proposed that FOF and fall episodes are interdependent. Specifically, individuals who experience a fall are more likely to develop FOF, and individuals who fear falling are at a greater risk of experiencing a fall (Friedman, Munoz, West, Rubin, & Fried, 2002). The amount of time since a fall incident has also been associated with the intensity of FOF (Jang, Cho, Oh, Lee, & Baik, 2007). A fall is initially likely to induce some fear about experiencing a subsequent fall. However as time passes, balance confidence could eventually be regained. Jang and colleagues (2007) reported a steady decrease in FOF levels over a three year period after the initial fall. Those who had fallen within the past three years were more likely to report FOF and restrict daily activities than those who had fallen more than three years ago. Those who fell in the past six months were up to seven times more likely to report FOF than those who had fallen more than six months ago (Jang, et al., 2007).

Of the many factors influencing FOF, age-related physical changes that result in compromised postural control may have substantial effects on balance confidence levels (Maki & McIlroy, 1996; Shumway-Cook & Woollacott, 2001). The following sections provide an overview of the current knowledge regarding postural control and the effect of aging.

1.2 Postural Control

The successful performance of ADLs requires stable and upright posture which is regulated by the sensory and motor systems. Three sensory systems (visual, vestibular and somatosensory) provide an indication of the current state of equilibrium via integrative sensory feedback by the central nervous system (CNS). The CNS directs the motor system to provide a response that will ensure that upright posture is maintained (Alexander, Shepard, Gu, & Schultz, 1992; Black & Nashner, 1985; Maki & McIlroy, 1996). Postural control (PC) is defined as the process by which the CNS and the musculature of the body coordinate to actively regulate the center of mass (COM) within the base of support (BOS) to keep the body in a stable position (Figure 1.2) (Alexander, et al., 1992; Maki & McIlroy, 1996). COM is the theoretical center of the total body mass used for the purpose of analyzing forces acting on the body (Maki & McIlroy, 1996), while BOS is the area of the supporting base provided by the feet planted on the support surface (Maki & McIlroy, 1996; Shumway-Cook & Woollacott, 2001). If the position of COM exceeds the boundaries of the BOS, equilibrium will be compromised (Maki & McIlroy, 1996).

Postural stability is often characterized by postural sway during quiet standing (Lin, Seol, Nusbaum, & Madigan, 2008). Postural sway is the movement of the COM within the BOS (Winter, 1995). In the laboratory setting, postural sway is characterized from the center of pressure (COP) signal. COP is the net vertical ground reaction force vector under the feet (Lin, et al., 2008). Some examples of common COP based measures of postural sway include:

- Root Mean Square (RMS) – The magnitude of the COP trajectory throughout the trial (Carpenter, Frank, & Silcher, 1999).
- Mean COP Velocity – The average velocity of COP throughout the trial (Lin, et al., 2008).
- Elliptical Sway Area – The area covered by COP trajectory throughout the trial (Doumas, Smolders, & Krampe, 2008).

Increases in these COP-based measures are interpreted as a deterioration of postural control. For example, Carpenter and colleagues (1999) noted that removing vision during quiet standing resulted in increased RMS of the COP. The removal of vision during quiet standing also resulted in increased mean COP velocity in elderly subjects (Marigold & Eng, 2006). In addition, older adults have demonstrated poorer postural stability compared to younger adults as indicated by greater ESA performance scores for the older adults which was accentuated by the reduction of somatosensory feedback (Doumas, et al., 2008).

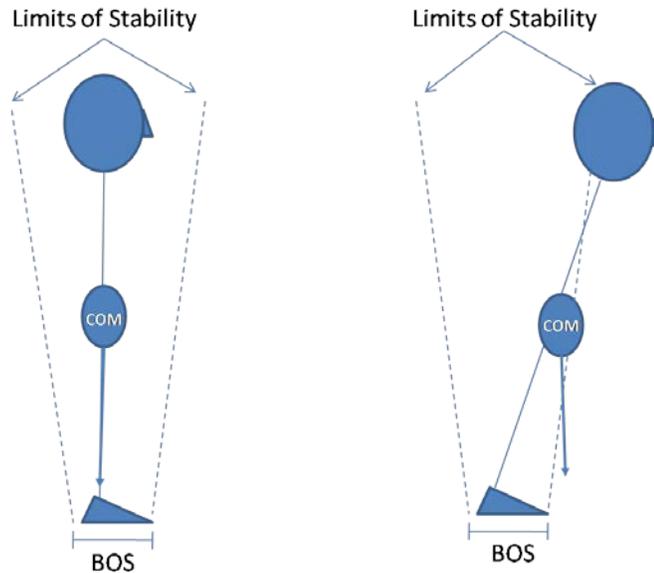


Figure 1.2 Stable posture requires the center of mass to remain positioned within the limits of the base of support (adapted from Maki & McIlroy, 2007; Nashner, 1982).

Forces, such as those induced by gravity and movement of the body, carry the potential to destabilize the body and must be counteracted by opposing muscle forces to ensure upright posture is sustained (Shumway-Cook & Woollacott, 2001). Winter (1995) described the human body as a “multilink inverted pendulum.” The larger and heavier mass of the body is situated on top of a smaller and lighter mass, and this mass pivots around the ankle joint (Winter, 1995). Postural stability relies on the CNS to determine the body’s orientation relative to its surroundings. Information regarding the orientation of the body is obtained from sensory receptors that provide feedback to the CNS about the internal and external environments (Nashner, 1982). Sensory information is received from three systems: visual, vestibular, and somatosensory. This information is integrated by the CNS to provide a representation of the position of the body in space (Nashner, 1982). The visual system provides a gravitational vertical of the body by determining the

position of the body in relation to the surrounding environment (Shumway-Cook & Woollacott, 2001). The vestibular system provides an indication of the orientation of the head relative to gravity (Nashner, 1982). The somatosensory system provides information about the supporting surface and the position of body segments in relation to one and other (Nashner, 1982; Shumway-Cook & Woollacott, 2001).

Sensory structures constantly provide the CNS with incoming information from all available sensory structures. This results in the replication of the same message about the environment and is regarded as “sensory redundancy” (Woollacott & Shumway-Cook, 2002). If one sense is compromised or removed (e.g. eyes closed), the CNS will reweight the priority of the feedback sources towards the remaining inputs to ensure that postural stability is maintained (Woollacott & Shumway-Cook, 2002). Age related declines in sensory acuity can reduce the opportunity for sensory redundancy. In turn, this can lead to an ineffective reweighting of available sensory inputs and ultimately increase chances of instability (Woollacott & Shumway-Cook, 2002).

1.2.1 Postural control and aging. Genetic predispositions and exposure to elements of our environment induce physiological changes that can affect us later in life (Shumway-Cook & Woollacott, 2001). These physiological changes, in turn, influence postural control and other motor abilities. For example, muscular strength is estimated to decrease nearly 10% per decade from ages 40 to 80 years (Aniansson, 1986) due to a decrease in muscle size and ratio of fiber types (Vandervoort, 1992). This loss of muscle mass also compromises muscular endurance (Medina, 1996). Reduced joint flexibility caused by arthritis and decreased elasticity of connective tissues leads to a more

prominent forward flexion of the head and pelvis and knees causing a stooped posture (Figure 1.3) (Roach & Miles, 1991).

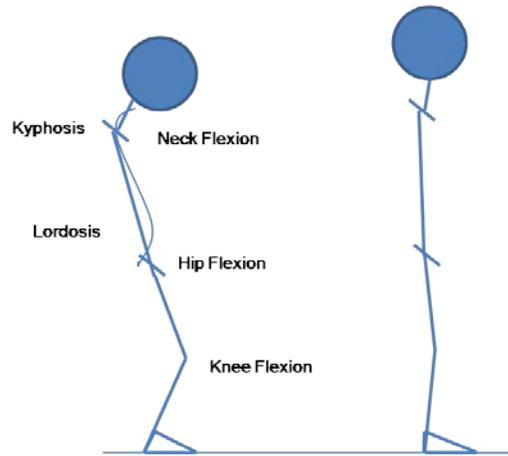


Figure 1.3 Example of stooped posture vs upright posture (figure adapted from Lewis, 1990).

Sensory receptors are also affected by aging. Afferent receptors under the skin decrease in both density and responsiveness, leading to a loss of tactile sensitivity and diminished quality of somatosensory feedback (Bruce, 1980). Compromised somatosensory signals lead to prolonged response times or inaccurate muscular recruitment patterns which may lead to compromised recovery to perturbations in older adults (Kenshalo, 1986; Stelmach & Worringham, 1985; Woollacott, Shumway-Cook, & Nashner, 1986). For example, Woollacott and Shumway-Cook (1986) demonstrated that older adults displayed a slower muscular response latency following a postural disturbance than younger adults. With substantial declines in somatosensory sensation, it is speculated that older adults compensate for this loss by increasing dependence on vision (Hytonen, Pyykko, Aalto, & Starck, 1993). However, the visual system also

experiences age related declines, such as a reduced visual field, visual acuity and contrast sensitivity, resulting in poor depth perception (Pastalan, Mantz, & Merrill, 1973; Pitts, 1982; Verrillo & Verrillo, 1985). Such visual declines can be a result of age related disorders such as cataracts or macular degeneration (Pastalan, et al., 1973; Pitts, 1982). When the somatosensory and visual systems provide conflicting or insufficient sensory information, the vestibular system becomes the primary sensory source to ensure adequate sensory feedback (Black & Nashner, 1985). Yet vestibular sensitivity decreases up to 40% by the age of 70 due to the degeneration of hair cells within the semicircular canals, vestibular ganglion cells and nerve fibers (Paige, 1991; Rosenhall & Rubin, 1975). Together these age-related changes to sensory structures contribute to a greater risk of instability in aging adults (Rosenhall & Rubin, 1975).

1.2.2 Postural control in older adults who fear falling. Early postural control studies neglected to acknowledge FOF as an influential factor for balance performance in older adults (Maki, et al., 1991). Anxiety towards falling may influence postural responses during testing. If FOF is not accounted for, results may be misinterpreted (Maki, et al., 1991). For example, Maki and colleagues (1991) found no significant difference in postural performance between a population of fearful and non-fearful independently living older adults when standing quietly in non-challenging situations. However, when asked to close their eyes, fall-fearful adults displayed greater postural instability compared to non-fearful adults. Timed one legged stance tests were also compromised among the FOF group. Poor test results could be inferred as postural deficits in the FOF group. However, Maki argued that it is highly likely that removing

vision and the challenging one-legged stance could increase awareness of the susceptibility of falling, and subsequently impose modifications to postural control.

In a follow-up study (Maki, Holliday, & Topper, 1994), it was revealed that challenging postural tasks differentiate postural performances of fearful and non-fearful older adults. Specifically, no alterations in postural control were noted between groups during a non-challenging postural task. However, when standing on an unstable surface fall-fearful individuals displayed tighter control of postural sway than non-fearful subjects as indicated by smaller RMS amplitudes. Similar findings of reduced center of pressure displacement indices were noted in fall-fearful subjects when performing an abrupt deceleration task (Okada, Hirakawa, Takada, & Kinoshita, 2001). This tighter regulation of postural stability among fearful subjects may reflect increased muscle tension imposed by the CNS in an effort to reduce fall risk in threatening situations (Maki, et al., 1991, 1994; Okada, et al., 2001).

Findings of tighter postural control caused by the threat of instability are further substantiated by an extensive line of evidence that has demonstrated that improved postural control is mediated by increased ankle joint stiffness among non-fearful individuals placed in situations that imposed a threat to balance (Adkin, Frank, Carpenter, & Peysar, 2000; Brown, Sleik, Polych, & Gage, 2002; Carpenter, et al., 1999). Numerous studies (Adkin, et al., 2000; Brown & Frank, 1997; Brown et al., 2002; Carpenter, et al., 1999) have induced postural threat by placing subjects on the edge of a raised platform. Subjects displayed better postural stability as indicated by a reduction in RMS of the COP when standing at the edge of the raised platform than when standing in the middle or when on the ground. The current theory to explain these findings is that subjects gauge

the level of threat to posture, and that the CNS responds accordingly to minimize fall risk through modifications to postural regulation (Davis, Campbell, Adkin, & Carpenter, 2008). Non-fearful subjects in the work by Maki and colleagues displayed greater amounts of postural sway compared to fall-fearful subjects on the unstable surface. It is possible that the fall-fearful subjects perceived the unstable surface as a greater threat to stability than non-fearful subjects, and altered their posture to avoid further instability (Maki, et al., 1994).

The pervasive effect that fear of falling has on postural control provides a foundation for the current theory that cognitive mechanisms are involved in maintaining postural control (Brown, Shumway-Cook, & Woollacott, 1999; Huxhold, Li, Schmiedek, & Lindenberger, 2006; Kerr, Condon, & McDonald, 1985; Marsh & Geel, 2000; Shumway-Cook, Baldwin, Polissar, & Gruber, 1997; Teasdale, Bard, LaRue, & Fleury, 1993). The following section of this literature review provides an overview of the cognitive mechanisms that are pertinent to this thesis.

1.3 Executive Function and Attention

Executive function (EF) is defined as a set of cognitive skills responsible for initiating and monitoring actions and behaviors of daily activities (Lezak, 1995; Royall, et al., 2002; Yogev-Seligmann, Hausdorff, & Giladi, 2008). One component of EF is attention, which is described as “a mechanism of limited capacity that facilitates perceptual discrimination of stimuli” (Posner, 1978, p. 153). This term is used to encompass a number of processes including:

Selective Attention: Selective attention is the filtering and processing of relevant sensory information while disregarding irrelevant stimuli (Rogers, 2006). Selective attention is

affected by how difficult it is to distinguish a specific target from all other incoming stimuli within the environment. For example, a visual search paradigm is easier when objects contrast the target compared to when they look similar as shown in Figure 1.4 (Rogers, 2006).

| | |
|-----------|-----------|
| O O O O O | P P P P P |
| O R O O O | P P P P P |
| O O O O O | P P P R P |
| O O O O O | P P P P P |

Figure 1.4 Visual search paradigm. Searching for the “R” on the left should be easier than on the right as it is less similar to the distracting information (adapted from Rogers, 2006).

Focused Attention: Similar to selective attention, focused attention also involves the disregarding of irrelevant incoming stimuli from the environment. However focused attention differs from selective attention because the individual knows where the target will appear requiring concentration and processing of information from a particular source (Rogers, 2006).

Sustained Attention: Sustained attention is the active processing of information over an extended time period. It is similar to focused attention, but vigilance to the task is required for a prolonged duration (Rogers, 2006).

Divided Attention: Divided attention is the performance of more than one task simultaneously (Rogers, 2006). It is thought that simple tasks can be performed successfully together, however as complexity of tasks increase, performance of one of both tasks may be compromised (Rogers, 2006).

A consistent finding is that older adults display greater performance deficits compared to young adults during the performance of complex cognitive tasks. The prevailing theory to explain this phenomenon is that aging compromises the capacity for attentional processing compared to younger adults. Due to this reduced attentional processing capacity, older adults are more likely to exhibit performance deficits in multitask contexts (Ble, et al., 2005; Rogers, 2006).

The role of attentional mechanisms in the regulation of posture was first established by Kerr and colleagues (1985). Subjects performed both spatial and non-spatial cognitive tasks while sitting or standing in a challenging stance. The challenging stance only affected performance on the spatial cognitive task, suggesting that cognitive spatial processes share similar neural pathways with postural processes (Kerr, et al., 1985).

1.3.1 Dual task paradigm. Findings from Kerr and colleagues (1985) provided foundation to explore the interplay between cognitive and motor processes of postural control. The contribution of attention to the regulation of postural control can be examined using the dual task paradigm. This paradigm requires subjects to perform a cognitive task while walking or standing still. Maintaining stable posture is regarded as the primary task, and the cognitive task is considered the secondary task (Woollacott & Shumway-Cook, 2002). If the simultaneous task performance results in the compromising of one or both tasks, then it is suspected that an interference of tasks processing has occurred (Brown, et al., 1999; Marsh & Geel, 2000; Shumway-Cook, et al., 1997; Teasdale, et al., 1993; Woollacott & Shumway-Cook, 2002). A number of theories have been developed to explain attentional processing in dual task situations

(Yogev-Seligmann, et al., 2008). These theories include the bottleneck theory, the multiple resource model theory, and the limited capacity theory which are described as follows:

Bottleneck Theory: The Bottleneck Theory suggests that a bottleneck is created when two tasks require the same processor causing information to be processed sequentially. A bottleneck is created when too much incoming information requires processing, and processing of the secondary task will be delayed until the processor is finished with the first task (McCann & Johnston, 1992; Tombu & Jolicoeur, 2003; Yogev-Seligmann, et al., 2008).

Multiple Resource Model Theory: The Multiple Resource Model Theory proposes that attentional processing requires a number of resources. Interference while multitasking only occurs if both tasks share a common resource. If that is not the case, then dual task interference shall not occur and both tasks are performed successfully (Pashler, 1994; Yogev-Seligmann, et al., 2008).

Limited Capacity Theory: The Limited Capacity Theory suggests that attentional processing resources are limited in capacity. Therefore, if the performance of two attentionally demanding tasks surpass the threshold of that particular processor, a diminished performance of one or both tasks will result (Kahneman, 1973; Tombu & Jolicoeur, 2003; Yogev-Seligmann, et al., 2008). It is speculated that attentional priorities are dynamic and can be voluntarily shifted according to perceived task demands (McLeod, 1977). Thus the specificity of instructions given to subjects is crucial to the outcome of the study (Mitra, 2003; Tombu & Jolicoeur, 2003).

Although there are differing opinions on which theory best explains attentional processing during dual tasking (Yogev-Seligmann, et al., 2008), much of the literature adheres to the Limited Capacity Theory (Tombu & Jolicoeur, 2003). From the Limited Capacity Theory (Kahneman, 1973), methodology in dual task research follows three underlying assumptions:

1. There is a limited amount of central processing capacity,
2. The performance of a task uses a portion of the limited processing capacity,
3. If two tasks share the processing capacity, performance of one or both tasks will be compromised if the limited processing capacity is exceeded (See Woollacott & Shumway-Cook, 2002 for review).

1.3.2 Factors influencing the cognitive reinforcements of postural control. A number of studies have indicated compromised cognitive processing performance due to increasing postural challenge (Hunter & Hoffman, 2001; Kerr, et al., 1985; Lajoie, et al., 1996; Marsh & Geel, 2000; Teasdale, et al., 1993). The type of secondary task is also crucial to the impact of the cognitive task interference during the dual task paradigm. Kerr and colleagues (1985) established that performance of visual-spatial tasks was significantly compromised when standing in a difficult posture, but the performance of verbal recall tasks are not. This finding, later validated by Maylor and Wing (1996), suggests that the neural pathways used by spatial processing are also vital to the maintenance and monitoring of postural control (Kerr, et al., 1985; Maylor & Wing, 1996).

Equally likely is that postural control is compromised by a concurrent cognitive task (Brown, et al., 2002; Dumas, et al., 2008; Kerr, et al., 1985; Marsh & Geel, 2000),

an effect that is more pervasive among older adults than young adults (Brown, et al., 2002; Dumas, et al., 2008; Marsh & Geel, 2000). For example, a recent contribution by Dumas and colleagues (2008) demonstrated that older adults increased instability by approximately 40% when a secondary cognitive task was introduced, but that young adults showed no differences in postural stability with the inclusion of the cognitive task. Interestingly, as challenge to posture increased, no further decrement in postural control was noted in either young or old adults, but performance of the cognitive task was significantly compromised for older adults. Decrements in the performance of both tasks for older adults suggest that attentional capacities were exceeded and that older adults prioritized the performance of one task at the expense of another. In this case it appears that older adults prioritized postural stability to prevent the chance of a fall (Dumas, et al., 2008).

1.3.3 Attentional prioritization in dual task. Numerous studies have demonstrated that older adults show a prioritization of postural stability at the expense of cognitive task performance in dual task contexts (Brown, et al., 2002; Dumas, et al., 2008). Because subjects are not given specific instructions on how to prioritize attentional allocation in these studies, it appears that older adults adopt an automatic postural prioritization, perhaps to avoid instability (Brown, et al., 2002; Dumas, et al., 2008).

The Limited Capacity Theory dictates that if the attentional resources used to perform multiple tasks exceed the available reserve, then task performance will be compromised (Kahneman, 1973). Recently, Siu and Woolacott (2007) proposed the possibility of a dynamic and flexible reciprocity in the prioritization of attentional

resources between postural and cognitive tasks. The researchers tested this theory by exploring the ability of younger adults to deliberately allocate attentional resources between postural and cognitive task performance. During quiet standing, subjects were given specific instructions on which task to prioritize attention towards (postural priority, cognitive task priority, or equal priority between posture and cognitive tasks). Cognitive performance scores varied in accordance with instructional set, but no differences were found in measures of postural stability across different instructions. These findings suggest that young adults have sufficient attentional resources to maintain a stable posture even when the cognitive task is prioritized (Siu & Woollacott, 2007).

A limitation of the study by Siu and Woollacott (2007) was that the postural and cognitive tasks may not have been challenging enough to elicit prioritization. Mitra and Fraizer (2004) addressed this issue of prioritization in a similar study by instructing subjects to prioritize attentional allocation while performing increasingly difficult postural and cognitive tasks. Posture was manipulated by using a wide stance and a narrow stance, while the cognitive task was manipulated by increasing the number of objects in the visual search paradigm. Subjects were given two instructional sets: Prioritizing the cognitive task, or equally prioritizing the cognitive and postural task. When asked to equally prioritize both tasks, subjects were able to increase stability regardless of the postural challenge. Interestingly though, stability was somewhat compromised when the cognitive load was increased (Mitra & Fraizer, 2004). These results provide further evidence that young adults exhibit the ability to prioritize the allocation of attentional resources. An essential component of dual task paradigms that has been overlooked in past studies is the sensitivity of subjects to the inconsistent

protocols and instructions. Comparisons of dual task research must be approached cautiously due to the fact that the use of differing instructional sets and protocols produce many outcomes (Mitra & Fraizer, 2004; Siu & Woollacott, 2007; Verghese, et al., 2007).

A common speculation is the possibility that the physical ability and attentional capacity of younger adults is adequate to provide sufficient attentional resources to both tasks. Therefore, concurrent task performance can be achieved without detriment to either task in the younger population (Mitra & Fraizer, 2004; Siu & Woollacott, 2007). This theory raises question of whether older adults can sustain the ability to allocate attentional resources given that greater attentional processing resources are dedicated to posture compared to younger adults. Recent research by Verghese and colleagues (2007), found that older adults also appear to demonstrate flexible prioritization of attentional tasks during a dual task paradigm involving walking and talking (Verghese, et al., 2007). When older adults were asked to focus on the cognitive task, cognitive performance improved but walking speed was significantly reduced compared to situations of equal priority between tasks.

1.4 Summary

Fear of falling is a serious health concern for a large percentage of the growing senior community due to the confirmed association with fall risk (Hadjistavropoulos, et al., 2007). In addition, an increase in FOF can lead to debilitating lifestyle changes, decreased quality of life, and loss of functional independence. Research evidence to date has confirmed that the motor contributions to postural control differ between fall-fearful and non-fearful older adults (Maki, et al., 1991, 1994; Okada, et al., 2001). Yet beyond our own recent contributions documenting differences in selective attentional processes

for fall-relevant stimuli (Brown & White, submitted), there is currently no work to determine whether cognitive processes inherent to postural control are affected when fear of falling is present. It is essential to gain a better understanding regarding the attentional contributions to postural control in individuals who fear falling so that we may develop and implement new coping strategies and intervention programs for this at risk population.

Chapter 2: Objective of Thesis

2.1 Theory

Framed within the Limited Capacity Theory of attentional processing (Kahneman, 1973), the theory tested in this thesis was that fear of falling is associated with altered cognitive mechanisms necessary for postural control.

2.2 Objective

The objective of this thesis was to compare the cognitive mechanisms relevant to postural control between fall-fearful and non-fearful older adults. To achieve this objective, I examined the effects of increasing postural challenge on attentional mechanisms using two experiments. Experiment one examined the effect of increasingly difficult postural situations on attentional processing. Experiment two explored the potential for flexibility in attentional prioritization between postural and cognitive tasks under non-challenging and challenging dual task situations. To better understand attentional impact of FOF, both experiments compared performance scores between older adults who identified a fear of falling and those who did not identify having this fear.

2.3 Hypotheses

2.3.1 Experiment 1: Does fear of falling alter attentional demands during postural control? Exploring the effect of increasing task challenge. Older adults who fear falling will differ in attentional processing relevant to postural control compared to non-fearful adults. Specifically, fall-fearful individuals will display delayed verbal reaction times compared to non-fearful individuals when postural challenge increases.

2.3.2 Experiment 2: Does fear of falling alter prioritization of attentional processes when postural challenge increases? Fall-fearful older adults will show compromised flexibility in the prioritization of attentional resources between postural and cognitive tasks compared to non-fearful older adults. Subjects who fear falling will display longer reaction times but smaller sway areas than non-fearful subjects regardless of instructions, and effects will be magnified when posture is challenged. In contrast, non-fearful subjects will be able to comply with instructions and reduce postural sway or decrease response times according to instructional set. This will be apparent in both non-challenging and challenging postural conditions.

Chapter 3: Experiment 1- Attentional Demands Of Postural Control: Exploring the Effect of Challenging Postural Tasks among Older Adults Who Fear Falling

3.1 Abstract

Current knowledge suggests that altered motor mechanisms may contribute to the increased fall prevalence noted among older adults who fear falling. A possible contribution to these altered motor mechanisms is differing cognitive contributions to postural and locomotor control in fall-fearful older adults. The purpose of this study was to examine the attentional contributions to postural control during challenges to upright standing in older adults who fear falling. Twenty-three older adults were differentiated into two groups based on a self-reported fear of falling (n=11 FF; n=12 NF). Verbal reaction time (VRT) to a visual stimulus and the magnitude of postural sway (Elliptical Sway Area; ESA) were assessed during four manipulations to support surface conditions: (1) Firm, (2) Foam, (3) Positive Sway Reference (SR⁺¹), and (4) Double Gain Negative Sway Reference (SR⁻²). Groups did not differ in ESA scores and both demonstrated a significant increase in ESA for all support surface conditions compared to the Firm condition. FF displayed significant increases in VRT on both SR⁺¹ and SR⁻² compared to the Firm surface while NF did not display changes in VRT across conditions. Fear of falling may alter attentional processes relevant to balance control, particularly under situations of postural challenge. This finding presents the possibility that those who fear falling may accommodate to challenging balance situations by altering the cognitive strategy for regulating balance.

3.2 Introduction

Although once presumed to be an automatic process, it is now well established that postural control requires attentional processing (Andersson, Yardley, & Luxon, 1998; Brown, et al., 2002; Dumas, et al., 2008; Faulkner, et al., 2006; Kerr, et al., 1985; Lajoie, Teasdale, Bard, & Fleury, 1993; Marsh & Geel, 2000; Redfern, Jennings, Martin, & Furman, 2001; Teasdale, et al., 1993; Woollacott & Shumway-Cook, 2002). Dual task paradigms in which a cognitive task is performed concurrent to a postural task are used to provide inference of the attentional dynamics inherent to postural control (Lajoie, et al., 1993; Siu & Woollacott, 2007; Woollacott & Shumway-Cook, 2002). Interpretation of dual task performance is based on the Limited Capacity Theory (Kahneman, 1973). The premise of this theory is that performing each task (i.e. postural and cognitive tasks) requires attentional resources, and that these attentional resources are finite in availability. In this scenario, execution of multiple tasks may surpass the attentional processing capacity and lead to performance decrements in one or multiple tasks (Kahneman, 1973).

The allocation of attentional resources during concurrent postural and cognitive tasks has been extensively studied across numerous clinical and non-clinical populations (Bloem, Grimbergen, van Dijk, & Munneke, 2006; Brown, et al., 2002; Mitra & Fraizer, 2004; Reilly, Woollacott, van Donkelaar, & Saavedra, 2008; Siu & Woollacott, 2007; Verghese, et al., 2007). Of particular relevance, a substantial body of literature has found that older adults demonstrate greater disruptions to cognitive performance than younger adults when in challenging postural situations (Alexander, et al., 1992; Brown, et al., 2002; Lajoie, et al., 1996; Marsh & Geel, 2000; Redfern, et al., 2001; Teasdale, et al.,

1993). For example, Teasdale and colleagues (1993) showed that older adults demonstrated compromised reaction time scores when standing on a compliant foam surface compared to standing on a firm floor. This decrement to reaction time was not apparent in young adults (Teasdale, et al., 1993). Such findings have led to the interpretation that older adults require greater amounts of attentional resources for postural regulation than young adults (Brown, et al., 2002; Doulmas, et al., 2008; Lajoie, et al., 1996; Marsh & Geel, 2000; Redfern, et al., 2001; Teasdale, et al., 1993).

Included within the older adult population are individuals who suffer from a fear of falling. Fear of falling affects over half of the senior population (Howland, et al., 1993; Maki, et al., 1991; Myers, et al., 1996; Tinetti, et al., 1994) and is associated with increased fall risk (Hadjistavropoulos, et al., 2007; Myers, et al., 1996). Motor regulation of postural control has been explored in this population and findings have revealed differences compared to non-fearful older adults (Maki, 1997; Maki, et al., 1991, 1994; Okada, et al., 2001). Specifically, fall-fearful participants demonstrated lower performance scores of postural stability during postural tasks such as standing with eyes closed or in response to abrupt platform deceleration (Maki, et al., 1991, 1994; Okada, et al., 2001). Although these data support an interpretation of compromised postural stability in fall-fearful older adults, little is known about the regulation of attentional contributions to postural control in this population. Given the confirmed interplay between attention and motor output (Bloem, et al., 2006; Reilly, et al., 2008; Snijders, Verstappen, Munneke, & Bloem, 2007), it is prudent to investigate this phenomenon among individuals who fear falling. Our laboratory is currently investigating attentional dynamics inherent to postural control among fall-fearful individuals and we have recently

demonstrated that individuals who fear falling show differences in selective attentional processing of fall-relevant stimuli compared to older adults who do not identify to have a fear of falling (Brown & White, submitted). This difference provides a foundation for the possibility that the role of attention for regulation of postural control may also differ in this population. Therefore, the purpose of this study was to compare the attentional contributions to postural control during challenges to upright standing between older adults who fear falling and those who do not have this fear.

3.3 Methods

3.3.1 Participants. The Human Research Ethics Committee of the University of Lethbridge granted approval of this study. Twenty-three community dwelling adults over the age of 60 ($M_{age} = 68.8 \pm 5.2$ yrs) responded to local advertisements seeking both fall-fearful (FF) and non-fearful (NF) adults. Prior to testing, participants voluntarily provided informed consent, and were assessed with a battery of questionnaires to verify adherence to qualifying criteria of; age over 60 years, cognitive function that was within normal limits (a score of >26 on the Mini Mental State Exam (MMSE; Folstien et al., 1975)), and independently ambulatory. Participants were excluded if they suffered from any known neurological or orthopedic disorder that would affect balance or cognitive abilities. Groups were differentiated as fall-fearful (FF; $n=11$; $M_{age} = 68.2 \pm 6.2$) or non-fearful (NF; $n=12$; $M_{age} = 69.4 \pm 4.3$) by self-reported fear of falling. Fear of falling was assessed using the short form Activity Specific Balance Confidence Scale (ABC-6; Peretz, et al., 2006), and trait anxiety was measured with the State Trait Anxiety Inventory (STAI; Spielberger, 1983).

3.3.2 Instruments and procedure. A NeuroCom® Clinical Research System (NeuroCom CRS; NeuroCom International, Inc. Clackamas, OR, USA) was used for all experimental trials. This apparatus consists of a three-sided visual surround, and dual locked mechanical force plates (AMTI®, Watertown, MA, USA), capable of translation or rotation in the sagittal plane about a central axis and within predetermined manufacturer specifications. Subjects wore a safety harness and stood facing a computer monitor built into the back wall of the visual surround for testing. Subjects were instructed to remain as still as possible while completing a choice verbal reaction time task (VRT) to a visual stimulus. The visual stimulus consisted of a solid black dot (diameter = 3cm) that appeared in the center of a white background on the computer monitor. The onset of the dot was programmed to appear randomly, at least five seconds after the trial commenced (Doumas, et al., 2008). Catch trials in which a solid red dot of equal diameter to the black dot were included in half of the trials to prevent habituation. Participants were asked to respond to the visual probe by saying the word “top” (Gage, Sleik, Polych, McKenzie, & Brown, 2003; Lajoie, et al., 1993). The meaning of this single syllable word is unrelated to the cognitive or postural tasks and begins with the hard consonant “T”, which is easily identifiable by auditory signal acquisition software. The onset of the visual stimulus was accompanied with an audible tone. This tone along with the verbal responses, were captured using a digital sound recorder worn by participants.

The NeuroCom CRS was used to manipulate the challenge imposed on upright standing. Subjects performed five trials on four different surface conditions for a total of 20 trials per subject. Each trial was 20 seconds in length. Conditions were block

randomized for each participant, and short breaks were given between conditions. The four surface conditions were: (1) Firm, (2) Foam, (3) Positive Sway Reference (SR^{+1}), and (4) a Double Gain Negative Sway Reference (SR^{-2}). Foam was used to create a compliant surface that decreased postural stability by limiting somatosensory inputs to the feet (Redfern, Moore, & Yarsky, 1997; Straube, Botzel, Hasken, Paulus, & Brandt, 1988). For sway referenced conditions, the supporting platform was servo-controlled to rotate in the anteroposterior direction about a central axis, proportional to the subjects' postural sway. A typical sway reference condition employs a gain of positive one (SR^{+1}), resulting in a platform rotation of equal proportion of to center of pressure displacement in the sagittal plane in the concurrent direction, thus compromising somatosensory inputs to the feet (Horak, Dickstein, & Peterka, 2002). To alter challenge to upright standing, the sway reference gain was doubled and presented with negative polarity (SR^{-2}). In this set-up, the support surface rotated in the opposite direction and with twice the amplitude of participants' postural sway.

3.3.3 Data analysis. Ground reaction forces and moments of force in three orthogonal axes were recorded at a sample rate of 100 Hz. These data were used to determine center of pressure position (COP) in the x and y planes and the Elliptical Sway Area (ESA) for COP movement during the 20 second test trial. These calculations were made off-line using a custom written MATLAB® program (Version R2008b; The Mathworks, Natick, MA, USA). ESA calculation was based on the principle components analysis method. In this technique, the magnitude of the ellipse areas were calculated from eigenvalues of the covariance matrix between COP in the x and y planes. Fitting to a 95% confidence interval, the ESA represents the area that would contain 95% of the

COP trajectories. A logarithmic transformation was applied to the ESA values to meet the normal distribution requirements for statistical analysis. Verbal reaction times were determined using Adobe Premiere Pro CS3® audio software (Version 3.2.0), and were defined as the latency from the onset of the visual stimulus to the onset of the verbal response. Transformations were not necessary for VRT scores as they met normal distribution requirements.

Demographics were compared between groups using independent *t*-tests. Two separate 2x4 [Group (FF/NF) x Condition (Firm/Foam/SR-/SR+)] Repeated Measures Analysis of Variance (RM ANOVA) were conducted to examine the effect of postural challenge on the ESA and VRT scores. Statistically significant results were examined using post hoc using *t*-tests where appropriate. Statistical significance was set at $p \leq .05$.

3.4 Results

3.4.1 Demographics. Group demographics and questionnaire scores are provided in Table 3.1. All participants who reported to be fall-fearful had ABC scores lower than the group median of 88.6%. Also, ABC scores were significantly lower in the FF group compared to the NF group [$t(21) = 7.5, p < .001$]. MMSE scores, age, number of falls in the past year, and trait anxiety did not differ between groups ($p > .05$).

Table 3.1 Group demographics (Means, SEs and *t* scores)

| | NF | FF | <i>t</i> |
|--------|------------|------------|----------|
| ABC 6 | 95.2 (1.3) | 61.3 (4.4) | 7.53** |
| MMSE | 29.3 (0.3) | 29.5 (0.2) | 0.30 |
| STAI-T | 31.0 (1.6) | 32.0 (1.6) | 0.400 |
| Age | 69.4 (1.3) | 68.2 (1.8) | 0.56 |
| Falls | 0.50(0.1) | 1.09(0.1) | 1.33 |

Level of significance is indicated by **, $p < .001$

3.4.2 Verbal reaction time task. Post hoc analysis of a significant main effect for Condition [$F(3, 19) = 5.07, p = .010$] revealed that VRT scores were significantly longer in the SR⁺¹ condition compared to the Firm condition [$t(22) = 3.34, p = .003$]. Nevertheless, a significant Group by Condition interaction [$F(3,19) = 3.76, p = .028$] indicated that the change in VRT scores across testing conditions was not consistent between groups. Specifically, VRT scores were significantly greater in the SR⁺¹ and SR⁻² compared to the Firm condition for the FF group [$t(10) = 4.0, p = .003, t(10) = 2.58, p = .028$ respectively], but no significant differences within the NF group were found across conditions ($p > .05$) (Figure 3.1).

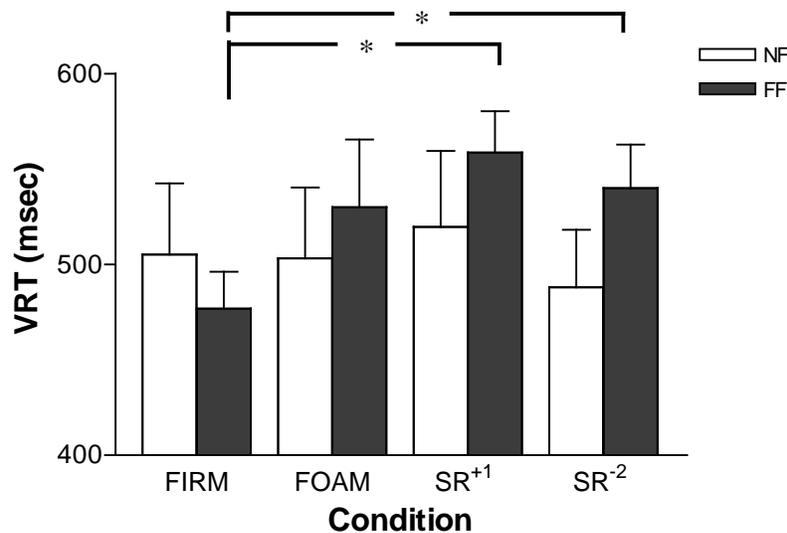


Figure 3.1 Verbal reaction times (msec) to verbal reaction time task plotted for each testing condition. Filled bars represent fall-fearful older adults, and empty bars represent non-fearful older adults.

3.4.3 Postural task. A main effect for Condition [$F(3,19) = 76.1, p < .001$] confirmed that significant differences were present between postural conditions (Figure

2). The Firm condition produced the smallest sway area with scores significantly less than Foam and SR⁺¹ and SR⁻² scores [$t(22) = 9.9, p < .001, t(22) = 9.1, p < .001, t(22) = 14.1, p < .001$ respectively]. SR⁻² produced the largest sway area with significantly higher scores than the Foam and SR⁺¹ conditions [$t(22) = 6.2, p < .001, t(22) = 8.8, p < .001$ respectively]. The Foam and SR⁺¹ conditions did not significantly differ from each other ($p > .05$). There were no significant Group or Group x Condition interaction effects.

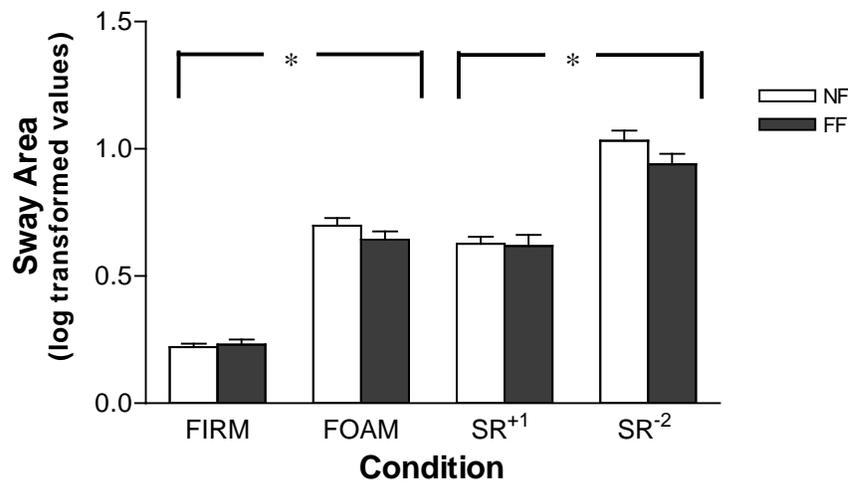


Figure 3.2 Transformed ESA for each testing condition. Filled bars represent fall-fearful older adults, and empty bars represent non-fearful older adults.

3.5 Discussion

The purpose of this study was to compare the attentional demands of postural control between older adults who fear falling and those who do not have this fear. To infer attentional demands, we compared the VRT scores obtained from FF and NF participants during postural tasks in which challenge to upright standing was varied. Our findings showed that only FF subjects demonstrated decrements to VRT scores as

postural challenge increased. However, groups did not differ in ESA scores across conditions of increased challenge to upright standing. Results imply that the increase in postural challenge results in a reorganization of attentional resources in older adults who fear falling, compromising the performance of the cognitive task.

A substantial body of literature (Brown, et al., 2002; Lajoie, et al., 1996; Redfern, et al., 2001; Teasdale, et al., 1993) has confirmed that postural challenge imposes decrements to cognitive performance in the dual task paradigm. In the current study, the secondary task decrement occurred for the fall-fearful group only during challenging postural tasks. Framed within the Limited Capacity Theory (Kahneman, 1973), this finding implies that fall-fearful subjects reorganize attentional resource priorities when the challenge to postural control increases. It is possible that the observed delay in VRT scores among FF is a consequence of a cognitive strategy in which attentional resources are consciously allocated to the regulation of postural control in order to heighten awareness about stability. Equally likely is the possibility that these attentional resources are directed allocentrically towards distracters within the external environment such as the visual surround, or background noise. Within this interpretation, it is interesting to note that the cognitive performance scores of NF subjects remained unchanged despite the increased postural sway as postural challenge increased. It appears that the non-fearful subjects did not reorganize attentional resource priorities in this study. Although this finding of consistent cognitive task performance despite increased postural challenge contrasts much of the current literature in dual task paradigms (Brown, et al., 2002; Kerr, et al., 1985; Lajoie, et al., 1996; Teasdale, et al., 1993), similar findings have been reported by others (Marsh & Geel, 2000; Redfern, et al., 2001). Redfern's work implied

that greater challenges of sensory integration (such as removing input from two sensory systems instead of one) resulted in the allocation of additional attentional resources to maintain stable posture (Redfern, et al., 2001). It is therefore possible that the challenging postural conditions used in the current experiment in which only somatosensory inputs were manipulated, did not elicit sufficient attentional resources to compromise the secondary task in NF subjects.

Another possibility for the absence of change in reaction time scores among NF subjects, also noted by Marsh and Geel (2000), was that the simplicity of the VRT task was insufficient to necessitate substantial allocation of attention resources to the cognitive task. Therefore it did not require near the quantity of cognitive resources that may be necessitated by a more challenging cognitive task such as a spatial memory task or visual search task (Kerr, et al., 1985; Marsh & Geel, 2000; Mitra & Fraizer, 2004). It is speculated that increasing the difficulty of the secondary task would have resulted in greater impairment to the cognitive task for both groups.

Previous research has revealed that older adults who fear falling performed poorer on postural performance indices compared to non-fearful older adults during tasks such as standing with eyes closed on a stable surface, or maintaining balance following an abrupt platform deceleration (Maki, et al., 1991; Okada, et al., 2001). However in situations of postural challenge, tighter regulation of postural control, as indicated by decreased RMS of the COP has been observed (Maki, et al., 1994). Contrary to expectation, our groups did not differ in postural performance scores. Although both FF and NF groups demonstrated greater postural sway with imposed challenge to upright standing, the magnitude of change was not group dependent. A possible explanation for

the absence of change between groups is that the postural conditions used for this experiment were not suitable for obtaining differences between groups, or that our measure of postural sway was insensitive to detect subtle differences occurring between groups.

Research protocols that impose a fear of falling by manipulating the level of postural threat have revealed that the perception of potential instability results in a tighter regulation of posture and leads to a reduction in postural sway (Adkin, et al., 2000; Brown, et al., 2002; Carpenter, et al., 1999). The absence of group differences for ESA scores may imply that both groups demonstrated similar increases in postural sway as challenge to upright standing increased, or that posture was not modified by groups in these particular experimental conditions. The key difference between groups was that FF suffered from a slowing to VRT while NF did not when postural challenge increased. It is our interpretation that fear of falling resulting in an altered organization of attentional resources under challenging postural conditions may result due to a diminished availability of attentional resources allocated towards the cognitive task.

3.6 Conclusion

Imposing challenges to upright standing resulted in compromised verbal response times in older adults who fear falling, however groups did not differ in measures of postural sway. Our findings suggest that there is a shift in attentional priorities towards maintaining a stable posture among FF subjects, which may have led to the compromised performance of the secondary cognitive task. Implications from these findings can be applied to daily situations such as walking on an uneven surface. With more attention being allocated to the maintenance of stability, FF individuals may be less aware of

potential dangers in the environment such as tripping hazards or potential disturbances to balance. Further inquiry into attentional contributions of postural control in those who fear falling is required to implement successful fall prevention programs.

Chapter 4: Experiment 2 - Attentional Task Prioritization in Older Adults who Fear Falling

4.1 Abstract

Contributions from attentional resources essential for the regulation of postural stability appear to differ between fall-fearful older adults (FF) and non-fearful (NF) older adults. The purpose of this study was to explore the potential for flexible attentional allocation between postural and cognitive tasks in older adults who fear falling. Twenty-one older adults were differentiated into two groups based on a self-reported fear of falling (n = 10 FF; n = 11 NF). A dual task paradigm using differing instructions of attentional allocation priority was used to examine cognitive and postural task performance. Results showed that both groups demonstrated prioritization of the postural task. However, only NF subjects demonstrated prioritization of the cognitive task while standing on a non-challenging surface. Neither group demonstrated attentional allocation flexibility for the cognitive task when challenge to upright standing was induced. Findings suggest that older adults who fear falling do not flexibly allocate attentional resources between postural and cognitive tasks. The absence of attentional allocation flexibility between tasks suggests that FF may be less able to attend to potential fall threats in the environment contributing to the increased fall risk in this population.

4.2 Introduction

Once thought to be an automatic process, it is now recognized that maintaining stable posture requires attentional resources (Andersson, et al., 1998; Brown, et al., 2002; Dumas, et al., 2008; Faulkner, et al., 2006; Marsh & Geel, 2000; Teasdale, et al., 1993). The Limited Capacity Theory dictates that these attentional resources are finite in capacity (Kahneman, 1973). Accordingly, simultaneously performing multiple attentionally demanding tasks could exceed the threshold of the processing capacity leading to compromised task performance (Kahneman, 1973). It is speculated that the allocation of attentional resources between tasks is dependent on the complexity of concurrent tasks, with more challenging tasks require greater attentional resources (Kahneman, 1973). Therefore, reduced attentional resources will be available for the less challenging task causing greater performance decrements (Karlin & Kestenbaum, 1968). Within the domain of postural control, results from dual task tests in which two attentionally demanding tasks (postural and cognitive) are performed at the same time have suggested that there are age related differences in the strategy of allocating attentional resources for these tasks (Brown, et al., 2002; Dumas, et al., 2008; Lajoie, et al., 1996; Marsh & Geel, 2000; Redfern, et al., 2001; Shumway-Cook, et al., 1997; Teasdale, et al., 1993). Specifically, older adults devote a greater proportion of available attentional resources towards maintaining stable posture than younger adults, consequentially reducing the remaining attentional resources available to complete the secondary task (Brown, et al., 2002; Shumway-Cook, et al., 1997). Since activities of daily living often necessitate concurrent performance of multiple tasks, it is possible that successful performance of these tasks may depend on the ability to flexibly switch

attention between tasks (Siu & Woollacott, 2007). Flexible distribution of attentional resources between concurrent tasks has been suggested as a strategy to aid in the successful performance of simultaneous attentionally demanding tasks (Siu & Woollacott, 2007). The “posture first” phenomenon, in which older adults inherently prioritize attentional resources for regulating postural control (Shumway-Cook, et al., 1997; Woollacott & Shumway-Cook, 2002) presents the possibility that flexibly allocating attentional resources may be difficult for the aging population. Recent research (Mitra & Fraizer, 2004; Siu & Woollacott, 2007) has established that in a dual task context, young adults can flexibly allocate attentional resources between the postural and cognitive tasks. For example, Siu and Woolacott (2007) had subjects perform a cognitive spatial memory task while standing still. The task was completed under three different instructional sets: (1) equal priority of attentional resources between cognitive and postural tasks, (2) cognitive task priority and (3) postural task priority. Findings indicated that subjects improved cognitive performance during the cognitive priority trials, but postural performance did not change across instructional sets. The authors suggested that subjects were able to dedicate sufficient attentional resources to maintaining posture even when the cognitive task was prioritized (Siu & Woollacott, 2007). It is arguable that the difficulty of the postural task (i.e. standing in a normal stance on a fixed surface) may not have been challenging enough to compromise prioritization between tasks. That is, subjects were able to devote sufficient attention to the cognitive task because the postural task did not require substantial attentional resources. Consequently, it is conceivable that the need for attentional allocation flexibility was not fully elicited by Siu and Woollacott’s study. This issue was addressed by Mitra and colleagues (2004) who

applied similar instructional sets, but with a manipulation of postural challenge and cognitive task loads. Results indicated that postural control improved with instruction despite the imposed postural challenge, however the increase in cognitive challenge compromised the magnitude of improved postural measures in both postural conditions. Taken together, these findings imply that the difficulty of both tasks influence flexibility of attentional allocation in younger adults (Mitra & Fraizer, 2004; Siu & Woollacott, 2007).

More recently, the inquiry of attentional allocation flexibility has been extended to the older population. Verghese and colleagues (2007) explored the effect of different instructional sets among older adults during a concurrent walking and talking task. Subjects displayed an ability to improve gait performance when asked to equally prioritize both tasks, however when asked to prioritize the cognitive task, there were no improvements in cognitive performance scores. The authors suggested maintaining stability during gait may have compromised the ability to prioritize the secondary cognitive task (Verghese, et al., 2007). Despite the absence of change in cognitive scores, the improvement in gait parameters noted during the equal priority instruction tasks substantiates the possibility that older adults are able to flexibly prioritize postural tasks.

Current research in our laboratory is exploring the attentional dynamics associated with postural control among older adults who fear falling. We have recently established that fall-fearful individuals differ in selective attentional processing to fall-relevant stimuli compared to non-fearful adults (Brown & White, submitted). Moreover in Chapter three, I demonstrated that postural challenge resulted in compromised performance on a reaction time task among fall-fearful subjects. This finding presented

the possibility that older adults who fear falling reorganize attentional resource priorities when challenges to posture increase, where as non-fearful older adults do not. While this may be a prudent strategy for postural regulation (Brown, et al., 2002), the opportunity also arises for reduced awareness of the environment unless a flexible allocation of attentional resources can be relied upon. Therefore, the purpose of this study was to explore the possibility for flexibility of attentional allocation between postural control and a concurrent cognitive task in older adults who fear falling. To increase the external validity of this study, this research question was applied in two conditions of postural challenge.

4.3 Methods

4.3.1 Participants. The protocol of this study was approved by the Human Research Ethics Committee of the University of Lethbridge. Eleven fall-fearful (FF; $M_{\text{age}} = 68.5 \pm 5.4$ yrs) and ten healthy non-fearful (NF; $M_{\text{age}} = 70.3 \pm 6.2$ yrs) adults were recruited through local newspaper advertisements to participate in this study and voluntarily provided informed consent prior to testing. Subjects were included in the study if they were over the age of 60, ambulatory, and free of any known neurological or orthopedic disorder that would affect their balance or memory. Subjects were also screened to ensure that they were free of dementia (a score of <26 on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and had good to moderate cognitive executive functioning abilities (a score of <156 s on the Delta Trail Making Test (ΔTMT^1 ; Coppin et al., 2006)). These assessments were made prior to

¹ ΔTMT = the difference between TMT task A and TMT task B (TMT B – TMT A), measured in seconds (Coppin et al., 2006).

testing. Additionally, fear of falling was rated using the Activity Balance Confidence Scale (ABC; Powell & Myers, 1995) and trait anxiety was measured with the State Trait Anxiety Inventory (STAI; Spielberger, 1983).

4.3.2 Procedure. The protocol of this study required subjects to perform a continuous cognitive task (Spatial Memory Task; SMT, described below) while standing still for a 30 second testing interval. The paradigm was performed under three instructional sets of task priority, and on two different support surface conditions. The instructional sets of task priority were:

Cognitive Priority (CP) – Subjects were instructed to focus attention to the SMT and respond as quickly and accurately as they could.

Postural Priority (PP) – Subjects were instructed to focus attention to their posture and stand as still as they could.

Equal Priority (EP) – Subjects were instructed to divide attention equally between tasks; responding as quickly and accurately as possible to the SMT while standing as still as possible.

The postural conditions were differentiated based on the dynamics of the support surface: Fixed support surface and a positive sway referenced support surface (SR). Instructional sets were performed on each support surface in a block randomized order. Subjects performed four trials in each testing condition totaling 24 experimental trials. Prior to testing, subjects performed a block of Verbal Reaction Time (VRT) trials on both support surfaces. These data were used to provide baseline cognitive performance score data for normalizing purposes (Siu & Woollacott, 2007).

4.3.3 Postural tasks. Subjects stood in a NeuroCom® Clinical Research System (NeuroCom CRS; NeuroCom International Inc., Clackamas, OR, USA) with dual locked mechanical force plates (AMTI®, Watertown, MA, USA) and a three-sided visual enclosure. A challenge to upright standing was presented for half of the test trials by support surface sway referencing. During sway referencing, the force plates are servo-controlled to rotate about a central axis in the anteroposterior direction in proportion to the subjects' postural sway. Past research protocols (Horak, et al., 2002; Shumway-Cook & Woollacott, 2000) have employed a sway referencing surface with a gain of positive one, in which the force plates rotate in exact proportion to center of pressure displacement in the sagittal plane, causing a reduction in somatosensory feedback from the feet (Horak, et al., 2002). A gain larger than one causes a greater displacement of the force plates, therefore resulting in greater instability (Doumas, et al., 2008; Reilly, et al., 2008). For that reason, a surface sway referencing gain of 1.5 was used in this study.

4.3.4 Cognitive tasks. The VRT task required subjects to respond with the word “top” as fast as possible when a visual stimulus appeared. The word “top” was used because the articulation of the hard consonant “T” is easily detected as the onset of the verbal response (Gage, et al., 2003; Lajoie, et al., 1993). The visual stimulus consisted of a blue square presented in the center of a black background that appeared twice at randomized times during each 30 second trial. Visual stimuli were created using a custom written slideshow (PowerPoint®) and were presented on a computer monitor built into the back of the visual surround. Subjects were given a practice trial to become familiar with the task and support surface prior to each novel condition. Three VRT trials were performed on both Fixed and SR support surfaces.

The Spatial Memory Task consisted of a sequence of visual presentations displayed on the monitor (Figure 4.1). Every trial began with a blue 5 x 4 grid (which filled the available space on the monitor) presented on a black background for 1000 milliseconds. The visual load consisting of a predetermined number of squares placed on the grid appeared for 3000 milliseconds. The squares then disappeared for 4000 milliseconds, after which time the stimulus probe consisting of two numbered squares appeared. Two probe square options were presented; one of the probe squares appeared in a space congruent to any of the squares presented during the prior load presentation, and the other probe square appeared in a position left vacant during the load presentation. Subjects were asked to articulate the congruent probe square using the number provided (“one” or “two”). The probe remained on the screen for 2000 milliseconds, after which the second SMT sequence would begin.

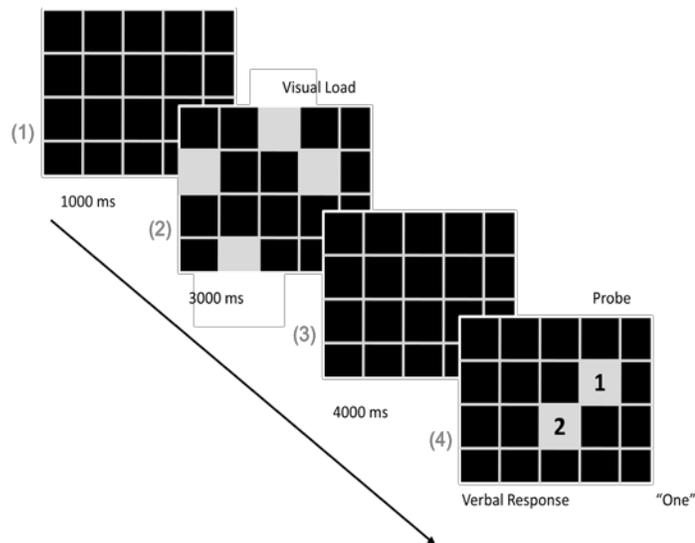


Figure 4.1 Diagram of the sequence of visual presentations for the Spatial Memory Task.

One sequence of the SMT consisted of four slides: (1) = Blank grid, (2) = Visual load,

(3) = Blank grid, and (4) = Visual probe.

To ensure that the cognitive task was equally challenging to all subjects, the attentional load of the SMT was normalized between subjects (Doumas, et al., 2008; Reilly, et al., 2008). For this reason, performance of the cognitive task for each participant was individually evaluated prior to testing. To achieve this goal, subjects first performed a series of titration trials to determine individualized levels for task difficulty (Reilly, et al., 2008). The initial titration trials presented two squares in the visual load, with the number of squares in the visual load eventually increased until accuracy was reduced to 80%. A maximum of six squares were shown during the load. Participants performed all titration trials while seated.

4.3.5 Data analysis. Center of pressure (COP) position in the x and y plane, and Elliptical Sway Area (ESA) for COP movement were derived from ground reaction forces and moments of force in the three orthogonal axes. A sampling rate of 100 Hz was used for each 30 second trial. A custom written MATLAB® program (Version R2008b; The Mathworks, Natick, MA, USA) was used to calculate ESA. This ESA calculation was based on the principal components analysis method in which the magnitude of the ellipse areas were calculated from eigenvalues of the covariance matrix between COP in the x and y planes. ESA was obtained using a 95% confidence interval. Accordingly, 95% of the COP trajectories were contained within the ESA for each trial. The initial five seconds of each trial were removed to compensate for initial stabilization. The remaining 25 seconds were used in the analysis.

VRTs were defined as the latency from the onset of the visual probe stimulus to the onset of the verbal response. VRTs from the spatial memory task were normalized

using the baseline VRT scores from the Fixed surface to minimize the impact of initial subject differences according to the following calculation:

$$\left(\frac{\left(\frac{\sum ET}{n} \right) - BL}{BL} \right) * 100$$

Where: $\sum ET$ = the sum of the four trials of a particular instructional set and floor condition, n = the number of trials, BL = the average baseline VRT scores on the Fixed surface.

Our interest in this study was to assess the effect of fear of falling on the potential for flexibility of attentional allocation between postural and cognitive tasks. To address this question we assessed postural and cognitive performance scores across two different priority instruction sets (PP and CP). We also explored this question using two support surfaces (Fixed and SR) to increase external validity. To eliminate bias between priority instructions, we included trials of equal priority within our experimental design. However, EP performance scores were excluded from the analysis but were provided as reference points on graphs.

4.3.6 Experimental design. A mixed model design with one between group factor and two within group factors was used in this study. The between group factor was Fear of Falling (NF, FF) and the within group factors included Instruction (CP, PP) and Support Surface (Fixed, SR). Three outcome variables were measured: Verbalized Response Times (msec), Accuracy (%), and Elliptical Sway Area (cm²).

Three separate mixed 3 factor 2x2x2 [Group (NF/FF) x Instruction (CP/PP) x Support Surface (Fixed/SR)] Repeated Measures Analysis of Variance (RM ANOVA) were conducted to investigate the effect of differing instructions and floor conditions for each outcome variable (VRT, Accuracy, and ESA). Significant results were further examined using mixed 2 factor 2x2 [Group (NF/FF) x Instruction (CP/PP)] for each support surface, followed by *t*-tests where appropriate. Statistical significance was set at $p \leq .05$.

4.4 Results

4.4.1 Demographics. Detailed group characteristics are summarized in Table 4.1. Subjects were categorized as FF or NF based on a self-reported fear of falling. Scores for the ABC questionnaire differed between groups [$t(19) = -7.4, p < .001$] with NF scoring significantly higher than FF. Scores for MMSE, Δ TMT, STAI, age and falls in the past year did not differ significantly between groups ($p > .05$).

Table 4.1 Group Demographics (Means, SEs and *t* scores) for screening questionnaires.

| | NF | FF | <i>t</i> |
|--------------|------------|------------|----------|
| ABC | 94.5 (1.2) | 63.6 (4.0) | 7.38** |
| MMSE | 28.9 (0.3) | 29.5 (0.2) | 1.89 |
| Δ TMT | 49.7 (8.3) | 44.0 (4.8) | 0.61 |
| STAI_T | 29.6 (2.1) | 31.7 (2.0) | 0.83 |
| Age | 70.3 (1.9) | 68.5 (1.6) | 0.73 |
| Falls | 0.60 (0.3) | 1.10 (0.4) | 0.49 |

Level of significance is indicated by **, $p < .001$

4.4.2 Postural sway. The RM ANOVA for sway area (Figure 4.2) revealed significant interaction between Instruction and Support Surface [$F(1,19) = 8.50, p = .009$], as well as main effects for Instruction [$F(1,19) = 10.57, p = .004$] and Support

Surface [$F(1,19) = 24.41, p < .001$]. No effects for Group were noted. Further analysis using RM ANOVA were conducted for each Support Surface. Although a notable effect for Instruction was observed on the Fixed surface, the change in scores was not significant ($p > .05$). Nonetheless, when the difficulty of the postural task increased, a significant main effect for Instruction [$F(1,19) = 10.12, p = .005$] on the SR surface was revealed as both groups demonstrated significant reductions in ESA scores from CP to PP instructions.

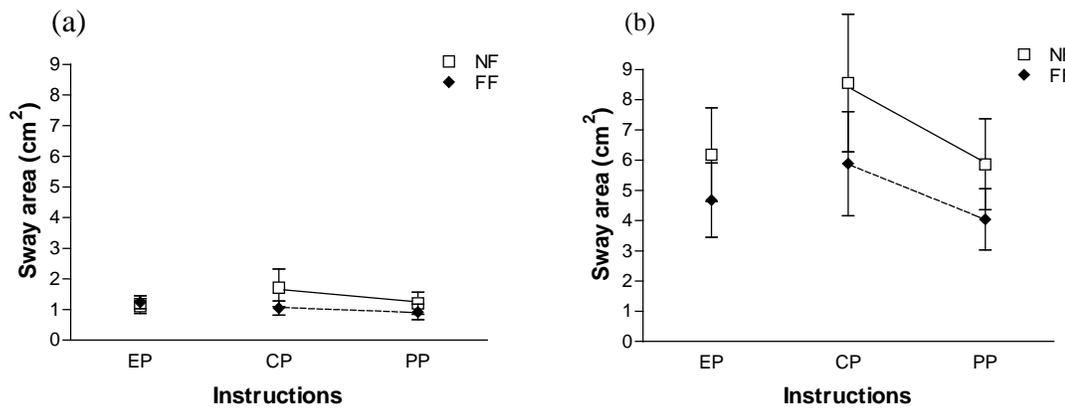


Figure 4.2 Mean postural sway as measured by Elliptical Sway Area (cm²) on Fixed (a) and SR (b) Support Surfaces for fearful (filled diamonds) and non-fearful subjects (open squares) during differing instructional sets. Instructional sets include: equal priority (EP), cognitive priority (CP), and postural priority (PP). EP is displayed as a reference point and was not used in the analysis.

4.4.3 Spatial memory task. The RM ANOVA for accuracy revealed no significance within or between groups ($p > .05$). Therefore only analysis of VRTs was considered for cognitive performance.

RM ANOVA for VRTs (Figure 4.3) revealed a significant Instruction x Support Surface x Group interaction [$F(1,19) = 4.86, p = .040$] as well as a significant Support Surface x Group interaction [$F(1,19) = .37, p = .012$]. A significant main effect was also revealed for Instruction [$F(1,19) = 4.53, p = .047$]. Further analysis within the Fixed surface revealed a significant main effect for Instruction [$F(1,19) = 4.20, p = .050$], and a significant Instruction x Group interaction [$F(1,19) = 4.17, p = .050$]. Comparisons of means indicated that RT scores increased significantly among NF, but not in FF subjects between CP and PP instructions on the Fixed condition [$t(9) = 2.17, p = .050$]. There were no significant main effects or interactions for the SR condition ($p > .05$).

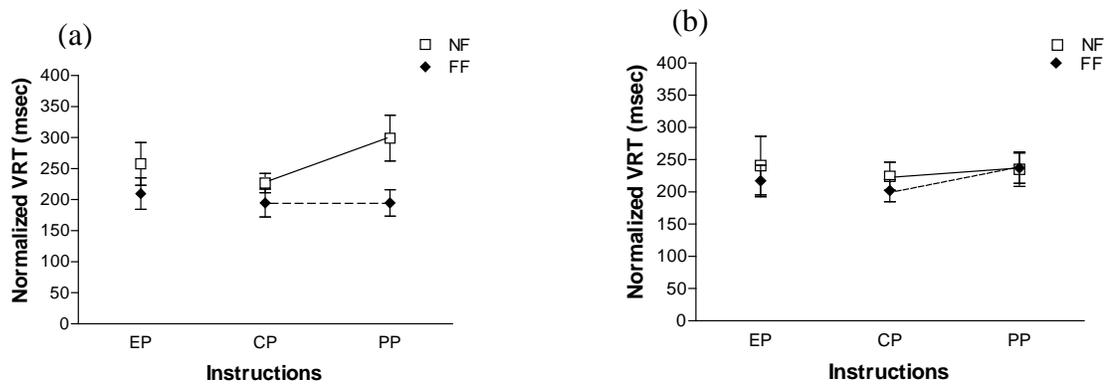


Figure 4.3 Normalized verbal reaction times for Spatial Memory Task on Fixed (a) and SR (b) Support Surfaces for fearful (filled diamonds) and non-fearful subjects (open squares) during different instructional sets. Instructional sets include: equal priority (EP), cognitive priority (CP) and postural priority (PP). EP is only displayed as a reference point and was not used in the analysis.

4.5 Discussion

The purpose of this study was to explore the potential for flexibility of attentional allocation in older adults who fear falling due two conditions of postural challenge. Participants were asked to maintain static posture while performing a SMT under three instructional sets (CP, PP, and EP) on two different support surfaces (Fixed and SR). Task performance was evaluated using ESA and VRT scores. Findings indicated that both groups were able to reduce postural sway when instructed to prioritize postural control over the cognitive task. However, only NF subjects were able to significantly improve response times when instructed to prioritize the cognitive task over the postural task, and only on the Fixed surface. Based on these findings, I have interpreted that fall-fearful subjects are unable to flexibly allocate attentional resources towards the cognitive task, but both groups are able to allocate attentional resources towards the postural task, and more so when the postural task is challenging.

4.5.1 Postural performance. The effect of instructions on postural priority was more evident on the SR surface than the Fixed surface. On the SR surface, both groups were able to significantly reduce ESA scores when instructed to prioritize posture. It is quite possible that the unstable surface elicited by sway referencing provided greater opportunity to rectify postural instability when instructed to prioritize posture. In contrast, this finding of reduced ESA scores was not as pronounced on the Fixed surface ($p>.05$). A possible reason for the absence of significance in the Fixed surface is that our measure of postural sway was not sensitive enough to detect minor changes in postural sway. Another possibility as suggested by Siu and Woollacott (2007) was that the combination of the Fixed surface and the stable stance (i.e. feet shoulder width apart),

may have limited the amount that subjects could further minimize postural sway when instructed to do so. However, the overall reduction in postural sway when given PP instructions indicates that both FF and NF subjects exhibit the ability to consciously regulate postural control, and suggests that those who fear falling can prioritize posture in dual task contexts. Our findings of the ability to prioritize the postural task are consistent with previous research in attentional prioritization (Mitra & Fraizer, 2004; Verghese, et al., 2007), in which both younger and older adults have displayed capability to significantly improve postural indices when instructed to prioritize posture.

An interesting finding from our postural data was that FF demonstrated smaller, though not significant, ESA scores than NF subjects in all conditions, particularly on the SR surface. Tighter control of postural sway in fall fearful older adults has been noted in previous research (Maki, et al., 1994). These authors suggested that FF subjects may attempt to minimize the risk of falling by minimizing postural sway through the co-contraction of antagonist muscles of the lower extremities. The phenomenon of reduced postural sway has also been noted amongst non-fearful subjects when fear of falling was induced by placing them in situations of postural threat, such as elevated surfaces (Adkin, et al., 2000; Brown et al., 2002; Carpenter, et al., 1999; Davis, et al., 2008). The reduction in postural sway area is thought to be caused by an increase in muscular tension brought on by the CNS when a situation is perceived as potentially threatening. In the current study, smaller sway areas displayed by FF subjects may indicate that FF perceived the conditions of postural challenge as a greater threat to stability than NF, causing them to minimize postural sway during all challenging postural situations. The attentional resources required to increase postural stability may reduce the limited

resources available for the performance of the secondary task. It is possible that FF subjects are more conscious of their postural stability compared to NF subjects, and therefore able to reduce sway to a greater extent which may lead to consequential decrements in cognitive attention during dual task situations.

4.5.2 Cognitive performance. Non-fearful subjects demonstrated the ability to significantly reduce VRTs from PP to CP instructional sets on the Fixed surface, while no significant differences in postural performance were found for these instructions. This reduction in VRTs suggests that non-fearful older adults can flexibly shift attentional resources towards the secondary cognitive task without compromising postural performance. Siu and Woolacott (2007) found that healthy young adults were able to direct attention towards the secondary cognitive task when standing on a firm surface. Their results suggested that young adults may automatically provide sufficient attentional resources towards maintaining balance, while enough resources remain available to improve performance of the cognitive task. In the present study, the reduction in cognitive VRTs was only evident in the NF group. Following the work of Woollacott and Shumway-Cook (2002), our findings imply that only NF subjects were able to allocate sufficient attentional resources to the cognitive task after sustaining stable posture. In contrast, absence of change in response times in FF subjects suggests that the maintenance of stable posture may compromise attentional resources available to prioritize the cognitive task in older adults who fear falling.

A curious finding was that fall-fearful subjects responded significantly faster on the SMT than non-fearful subjects when asked to prioritize posture on the Fixed surface. However, examination of accuracy for this particular condition revealed that NF subjects

obtained higher accuracy scores than FF subjects reaching near significance ($p = .06$). It is possible that FF were not concentrating on the cognitive task when asked to prioritize posture, resulting in the guessing of answers. Mitra (2004) suggested that subjects who feel uneasy during dual task situations may rush through the cognitive task at a minimal cost of compromising accuracy. This may explain the drop in accuracy in the FF group, and why the only NF displayed increases in VRTs to increased postural challenge.

Another interesting finding was that neither group was able to successfully improve SMT performance on the SR surface when given CP instructions. Findings from this study are comparable to results of Verghese and colleagues (2007), who noted that subjects were unable to significantly improve cognitive task performance when given instructions of cognitive task priority. It has been shown that increasing challenge to upright standing requires greater attentional resources for older adults to remain stable compared to non-challenging postural situations (Lajoie, et al., 1996; Marsh & Geel, 2000; Teasdale, et al., 1993). Therefore it is possible that regardless of the presence of FOF, cognitive task performance may be hindered when performed concurrent to a challenging postural task due to diminished available attentional resources.

4.6 Conclusion

My findings indicated that both FF and NF groups demonstrate the ability to flexibly allocate attentional resources towards prioritizing the postural task when instructed to do so. However, only NF subjects demonstrated the ability to prioritize the cognitive task, and only on the Fixed surface. Fall-fearful subjects on the other hand did not demonstrate the ability to prioritize the cognitive task on either support surface. These findings suggest that the attentional demands of maintaining postural stability in fall-

fearful older adults results in the inability to flexibly shift attentional resources towards prioritizing the cognitive task in dual task situations. Implications from my findings are that the strategy of egocentric allocation of attentional resources are allocated to posture in fall-fearful older adults may hinder the awareness of the environment. This could result in potential fall threats remaining unnoticed, and therefore posing a greater risk for falling.

Chapter 5: General Discussion

Current estimates suggest that fear of falling affects nearly half of the senior population (Brouwer, Musselman, & Culham, 2004; Howland, et al., 1993), and is associated with a heightened fall risk (Hadjistavropoulos, et al., 2007; Murphy, et al., 2002; Vellas, et al., 1997). With the increasing numbers of seniors in our communities, the development of intervention and prevention programs are necessary to reduce the impact of falls in this population (Brouwer, Walker, Rydahl, & Culham, 2003; Lui-Ambrose, Khan, Eng, Lord, & McKay, 2004; Tennstedt, et al., 1998). FOF is most problematic when individuals limit activities of daily living, thereby reduce physical function which in turn results in greater fall risk (Howland, et al., 1998; Murphy, et al., 2002; Vellas, et al., 1997). To date, postural control research on fall-fearful older adults has emphasized the physical motor contributions to postural control (Maki, et al., 1991, 1994; Okada, et al., 2001). Measures of postural control appear to differ in FF compare to NF subjects during postural tasks such as the one-legged stance task or abrupt deceleration tests in which FF demonstrated poorer indices of postural control than NF subjects (Maki, et al., 1991, 1994; Okada, et al., 2001). However, the underlying cause of these postural differences remains unclear. Considering the current literature on the attentional requirements of postural control (Brown, et al., 2002; Kerr, et al., 1985; Lajoie, et al., 1993; Teasdale, et al., 1993), it is appropriate to investigate attentional contributions for postural control in fall-fearful older adults. Exploration into the attentional contributions to posture in FF individuals may provide a better understanding of the underlying causes of altered postural control and increased fall risk in this population. This thesis is a contribution towards increasing knowledge about the

attentional mechanisms of postural control in older adults who fear falling. It is hoped that information from this thesis will contribute to the construction of more appropriate intervention programs for fall-fearful older adults.

5.1 Effect of Increased Postural Challenge on Attentional Contributions to Postural Control

The first experiment of this thesis examined the attentional contributions of postural control in fall-fearful and non-fearful older adults when challenge to upright standing was imposed. Attentional demands were assessed using VRT scores. Based on the Limited Capacity Theory (Kahneman, 1973), my hypothesis for this experiment predicted that FF subjects would demonstrate lower VRT performance scores than NF subjects, due to greater attentional resources being allocated towards reducing postural sway in the FF group when postural challenge was imposed. Due to this increased allocation of attentional resources towards postural control, I also predicted that FF subjects would demonstrate a smaller sway area than NF subjects when placed in challenging postural situations. In contrast to my hypothesis, there were no significant differences between groups for measures of postural sway (ESA) on any surface condition. Postural sway increased significantly for both groups from the Firm condition to the challenging postural conditions. However, only the fall-fearful group demonstrated significant increases in VRT scores as challenge to upright standing increased. Based on my findings, it appears that FF subjects may reorganize the allocation of attentional resources when postural challenge is increased, resulting in compromised cognitive task performance.

Findings of decrements to secondary task performance coincide with much of the current dual task literature (Brown, et al., 2002; Kerr, et al., 1985; Lajoie, et al., 1993; Teasdale, et al., 1993). Within the Limited Capacity Theory (Kahneman, 1973), it is interpreted that the compromised secondary task performance is caused by an inadequate reserve of available attentional resources after the primary task of maintaining balance is achieved. Although the protocol of the current study did not specifically assess the locus of attentional allocation (i.e. egocentric or allocentric), it is possible that FF subjects were directing greater amounts of attentional resources towards maintaining their balance than NF subjects. However it is also possible that FF subjects were allocating attentional resources externally towards visual or auditory distracters within the testing environment. The absence of increased VRT scores in the NF group concurrent with increased postural challenge may have occurred for a number of reasons. It is possible that the postural conditions used in this experiment were not challenging enough for the NF group to elicit a reorganization of attentional resources to maintain stability. It is also possible that the simplicity of the VRT task required minimal attentional resources, and therefore the allocation of attentional resources was not disrupted in this group.

Previous studies (Maki, et al., 1991, 1994; Okada, et al., 2001) have identified older adults who fear falling to display poorer indices of postural control than non-fearful older adults during postural tasks such as the one-legged stance or abrupt deceleration tests. Our measures of postural performance may not have been sensitive enough to detect minor differences between groups. However it is also possible that the postural conditions used in my experiment did not elicit a change in postural regulation in the FF group. My findings from this experiment suggest that challenges to upright standing

result in no differences in postural performance between FF and NF groups, but a reorganization of attentional resources appears to compromise cognitive task performance in older adults who fear falling when challenge to upright standing is present.

5.2 Allocation of Attentional Resources with Increasing Postural Challenge

The second experiment of this thesis investigated the possibility of flexible attentional allocation between cognitive and postural tasks in fall-fearful older adults during two postural conditions (Fixed and SR). Following the Limited Capacity Theory (Kahneman, 1973), I hypothesized that FF older adults would show compromised performance in the flexible allocation attentional resources between cognitive and postural tasks. Specifically, I proposed that FF subjects would not demonstrate any change in performance on either postural or cognitive tasks when instructed to prioritize a specific task. My premise for this hypothesis was based on the findings of Maki et al (1994) who noted that fall-fearful subjects demonstrate smaller measures of postural sway than NF subjects when challenge to upright standing was imposed.

In accordance with my hypothesis, fall-fearful subjects did not demonstrate prioritization of the cognitive task as indicated by the absence of reduced VRTs on the SMT when given instructions of CP. On the other hand, it was noted that NF subjects demonstrated the prioritization of the cognitive task on the Fixed surface only. In contrast to my hypothesis, both FF and NF subjects successfully prioritized the postural task (particularly on the SR surface) which was inferred by reduced ESA scores when given instructions of PP. Findings from this study imply that fall-fearful older adults do not flexibly allocate attentional resources between postural and cognitive tasks. On the

contrary it seems that a significant proportion of the limited attentional resources maybe dedicated to maintaining stability at the cost of the secondary task.

An interesting finding from this experiment was that FF subjects demonstrated smaller, though not significant, ESA scores than NF subjects, especially in the SR conditions. Reductions in postural sway have been noted amongst FF subjects when placed in situations of postural challenge (Maki, et al., 1994). Similar findings have been elicited amongst non-fearful subjects when placed in situations of postural threat (Adkin, et al., 2000; Brown, et al., 2002; Carpenter, et al., 1999; Davis, et al., 2008). A possible explanation for this reduction in postural sway is that participants experience an increase in muscular tension, resulting from the co-contraction of antagonist muscles in the lower extremities during threatening conditions (Adkin, et al., 2000; Brown, et al., 2002; Carpenter, et al., 1999). Following this reasoning, the smaller ESA scores demonstrated by the FF group may reflect the perception of the SR surface as a greater threat to stability than the NF group. This tighter regulation of postural sway also suggests that more attentional resources may have been allocated towards the postural task, which poses the potential to compromise the remaining attentional resources available for the performance of the secondary task.

Another notable finding was that neither group demonstrated prioritization of the cognitive task on the SR surface. Verghese and colleagues (2007) also noted an absence of cognitive prioritization when subjects performed a walking and talking task. Challenging postural tasks have been shown to require greater attentional resources (Brown, et al., 2002; Lajoie, et al., 1993; Marsh & Geel, 2000; Teasdale, et al., 1993). In the current study, the attentional requirements to maintain stable posture on the SR

surface appear to have compromised successful prioritization of the cognitive task in both FF and NF older adults. Therefore, regardless of the presence of fear of falling, a challenging postural task could potentially require substantial attentional resources that compromise the ability to flexibly allocate attentional resources towards the secondary task. My findings imply that the attentional demand of postural control reduces flexibility of allocating attentional resources between cognitive and postural tasks in older adults who fear falling. This reduced flexibility may result in a fixation of resources devoted to the postural task during dual task situations. Therefore, individuals who fear falling may be at an increased risk for falling as less attentional resources are dedicated to the awareness of potential threats to balance within the environment compared to non-fearful older adults.

5.3 Integrated Summary of Results

Results from both experiments of this thesis suggest that fall-fearful older adults demonstrate a reorganization of attentional resources pertinent to postural control. My first experiment demonstrated that challenge to upright standing resulted in both groups demonstrating similar increases in ESA scores for challenging postural conditions, but only fall-fearful subjects demonstrated decrements to VRT scores in when posture was challenged. These findings suggest that FF subjects reorganize attentional resources to maintain stable posture at the expense of the secondary task. My second experiment further demonstrated reorganization of the attentional contributions to postural control as FF subjects did not demonstrate improvements in cognitive task performance during CP compared to PP, while NF subjects demonstrated significant improvements for the CP task on the Fixed surface. Furthermore, with the increase in postural challenge, neither

group showed any improvement for the cognitive task from PP to CP instructions, but both groups significantly reduced ESA scores when given PP instructions compared to CP. My findings suggest that the challenging postural situations required a substantial amount of the limited attentional resources in order to maintain stability. Therefore both groups had limited attentional resources remained available for the performance of the cognitive task. Compromised cognitive task performance coinciding with a concurrent reduction in postural sway has been demonstrated in NF older adults when placed in situations of imposed postural threat (Brown, et al., 2002; Lajoie, et al., 1996). The current explanation of this phenomenon is that older adults automatically prioritize postural stability at the expense of the secondary task (Brown, et al., 2002).

Based on current research from our laboratory (Brown & White, submitted), a possible explanation for the reorganization of attentional resources in FF subjects may be due to differences in the attentional processing of emotionally-valenced stimuli compared to NF subjects (Brown & White, submitted). Using the dot probe paradigm, fall-fearful subjects demonstrated a greater difficulty in disengaging attention from fall-relevant words while NF did not appear to be affected by the same. Developed by Macleod and colleagues (1986), the dot probe paradigm is a common instrument used in the assessment of attentional processing of emotionally-valenced stimuli. The paradigm involves the presentation of word pairs on a computer monitor (one threatening, one neutral), followed by the appearance of a dot in place of one of the words. Subjects are required to press a key in response to the position of the dot and response times of the key press are collected (MacLeod, Mathews, & Tata, 1986). The present theory pertaining to the results of the dot probe indicates that subjects experience difficulty disengaging

attention from emotionally-valenced stimuli (Fox, Russo, Bowles, & Dutton, 2001; Koster, Crombez, Verschuere, & De Houwer, 2004). Thus, slower response times occur when the dot appears incongruent to the threatening word. Previous investigations of attentional processing have been assessed in various emotional conditions such as general clinical anxiety (Eysenck, 1992; Mogg & Bradley, 1998), social anxiety (Mogg & Bradley, 2004), or specific fears such as fear of pain (Asmundson & Hadjistavropoulos, 2007) or animal and spider phobias (Fawzy, Hecker, & Clark, 2006; Hermans, Vansteenwegen, & Eelen, 1999; Rinck & Becker, 2006). Our recent findings that fall-fearful older adults demonstrate differences in attentional processing of emotionally-valenced stimuli substantiates the possibility that FF older adults may also differ in attentional contributions to postural control compared to NF older adults, and provide a foundation for the research questions of this thesis.

5.4 Clinical Implications

Fear of falling is multifaceted in construct (Hadjistavropoulos, et al., 2007; Kressig, et al., 2001; Murphy, et al., 2002). Therefore, individuals who fear falling may benefit from different interventions depending on the basis of their fear. As previously noted in my Review of Literature (Chapter 1), fear of falling may indirectly increase fall risk if it limits activities of daily living (Delbaere, et al., 2004; Hadjistavropoulos, et al., 2007; Howland, et al., 1998; Howland, et al., 1993; Lachman, et al., 1998; Murphy, et al., 2002; Vellas, et al., 1997). However recently noted by Hadjistavropoulos and colleagues (2007), FOF may also be directly detrimental to balance. The authors suggested that there may be an immediate negative effect on balance caused by a sympathetic response (i.e. increased heart rate and respiration). Therefore, if excessive fear alters attentional and

physiological mechanisms related to balance, then an intervention should target those aspects of balance as well as the fear itself. However if fear is present because of a realistic view of personal balance ability, then physical function may be a more appropriate target for intervention (Hadjistavropoulos, et al., 2007).

A number of interventions have been examined to date that aim to reduce fear of falling. Liu-Ambrose (2004) investigated the effect of three types of exercise programs (strength, agility, and stretching) in older women who fear falling. Both strength and agility interventions significantly reduced levels of FOF as well as improved physical function after the 13 week training program, however the stretching group showed no improvements in FOF or physical function. Brouwer and colleagues (2003) evaluated the effects of an exercise intervention compared to a risk identification educational program in FF older adults. Both programs significantly reduced fear of falling, but the exercise group also showed improvements in physical ability to shift body weight to their limits of stability indicating greater confidence when physically performing the task. Finally, Tennstedt and colleagues (1998) created a four week intervention program that addressed numerous aspects associated with fear of falling including group discussions, assertiveness training, exercise training and home assessments. Reductions of FOF and increased activity levels were recorded until approximately six months after the intervention, suggesting that booster sessions may be required to prolong positive effects.

Findings from these studies reveal the importance of multi-dimensional intervention programs for FF older adults. Our findings that FF older adults demonstrate reorganization in the allocation of attentional resources supports the use of an intervention targeting attentional allocation abilities in this population. However as

previous research has shown (Brouwer, et al., 2003; Tennstedt, et al., 1998), a cognitive intervention would be most effective if delivered concurrent with a physical exercise program to reinforce balance abilities.

5.5 Future Research

Results from this thesis have demonstrated that individuals who fear falling do not flexibly allocate attention towards prioritizing secondary cognitive tasks, even when challenge to postural control is minimized. This absence in flexibly allocating attentional resources may be a possible contributor to the increased fall risk in the fall-fearful population. Exploration into attentional allocation training may help FF older adults learn to redistribute attentional resources to successfully perform concurrent cognitive and postural tasks. Both younger and older adults have demonstrated the ability to improve in the performance of multiple cognitive tasks with practice (McDowd, 1986). More recently, it was demonstrated that older adults were able to make considerable improvements in cognitive dual task performance following attentional allocation training (Kramer, Larish, & Strayer, 1995). To my knowledge, there has been no research using attentional allocation training using postural dual task paradigms in individuals who fear falling. Therefore, a training program targeting FF individuals to redistribute attentional allocation between cognitive and postural tasks may contribute to a future fall prevention program.

A second possibility of future study involves the exploration of dynamic dual task situations, because most activities of daily living require movement about the environment. Gait characteristics have been shown to differ in the FF population (Maki, 1997). Specifically, FF older adults demonstrated a more cautious gait pattern by taking

shorter strides, and spending a longer duration in double limb support than non-fearful subjects. Therefore, my findings that attentional allocation flexibility differs in static conditions between FF and NF subjects could potentially extend to dynamic situations with further investigation. Gage and colleagues (2003) induced anxiety in non-fearful older adults with the use of a constrained elevated walkway. The authors' findings suggested that subjects increased attentional allocation towards their locomotion at the expense of the secondary task when postural threat increased. To date, dual task paradigms involving locomotion have yet to be examined in the FOF population. Obtaining information on attentional allocation during walking would provide further insight into attentional mechanism of postural control in older adults who fear falling.

5.6 Limitations

A number of limitations must be taken into consideration when interpreting the results from this thesis. First of all, the recruitment of subjects who fear falling poses a number of limitations in and of itself. The ABC questionnaire provides insight into the intensity of FOF expressed by individuals as subjects rank their confidence in daily activities from 0 (no confidence) to 100 percent (complete confidence) (Powell & Myers, 1995). Therefore findings from this thesis cannot be generalized to the general population as I could not randomly select fall-fearful individuals of randomized intensities of FOF. Even though it is likely that severely fearful individuals were less likely to volunteer for this study (Maki, et al., 1991), the small sample size encompassed a large range in FOF levels with ABC ranges of 44.9 % in FF group, and 13.3% in the NF group. Had there been a larger number of subjects I could have broken the FF group in to high-fearful and moderate-fearful groups to limit the impact of variability of levels of FOF. Another

occurrence that is common in FOF recruitment is an unequal gender distribution (Howland, et al., 1998; Murphy, et al., 2002). The majority of FF subjects who volunteered for these studies were female, and the NF groups contained more males due to subject availability. For this reason, gender comparisons were not made, but future research with larger subject numbers would be useful to examine postural and attentional differences between genders in FF older adults. A final limitation due to the small numbers of available subjects was the large age range among subjects. As stated in the literature review, aging adults experience substantial physical declines with increasing age (Shumway-Cook & Woollacott, 2001). Though both groups contained similar age ranges (60-80 years), the broad range of ages spanning across two decades may have contributed to the variability in subject performances for both cognitive and postural tasks in both experiments.

The second limitation was the potential that anxiety levels of subjects were altered due to the increase of postural challenge. As previously mentioned, the research setting removes the ability to avoid fears towards instability, and therefore anxiety may set in during trials of postural challenge. As anxiety levels were not measured during the experiment, we cannot directly correlate anxiety levels and task performances. Examining state anxiety after each trial using a Likert scale, or measuring physiological arousal characteristics associated with increases in anxiety levels such as galvanic skin conductance would have provided insight into whether anxiety was increased with postural challenge in either group. However, indirect measures of increased anxiety such as reduced postural sway and compromised cognitive task performance provided an

indication that anxiety may have interfered with regular attentional processing in FF older adults.

A final limitation (found in Experiment 2) arose from the SMT. With only two possible answers, subjects had a 50% chance of guessing the correct answer, even if they were not paying attention to the cognitive task. It was not possible to control for this, and verbal response times were likely affected by it. Originally the Brooks Spatial Task (1967) had been considered to be used as the cognitive task, but the complexity of this task may have been too difficult for some subjects to perform under the added stress of standing in a challenging situation. The possibility of a modified Brooks Spatial Task should be considered for future research to control for the guessing of answers.

5.7 Conclusion

The purpose of this thesis was to compare the attentional contributions to postural control between fall-fearful and non-fearful older adults. My findings suggest that individuals who fear falling distribute attentional resources between postural and cognitive tasks differently than non-fearful individuals. Specifically, findings from Experiment one indicated that imposed challenge to upright standing resulted in significant increases in VRT scores in FF subjects only, while both groups demonstrated similar increases in postural sway with increased postural challenge. I interpret these findings to indicate that fall-fearful older adults shift priorities in attentional resources towards maintaining stable posture, which may have caused decrements to the cognitive task performance. Results from the second experiment of this thesis found that non-fearful older adults demonstrated flexible allocation towards both postural and cognitive tasks, while fall-fearful older adults only demonstrated flexible allocation towards the

postural task. These findings further substantiate the possibility that fall-fearful older adults allocate greater attentional resources towards maintaining stable posture at the expense of the secondary task than NF older adults.

My findings support the theory that limited attentional resources are available for the performance of concurrent postural and cognitive tasks. In addition, they provide a contribution towards the investigation of attentional allocation flexibility in older adults. Together, I interpret the results of my thesis to indicate that FF older adults are unable to flexibly allocate attentional resources towards the secondary task once dedicated to postural task. Therefore the compromised performance of the secondary task arises due to a lack of available resources. Although results may infer that FF subjects reduce potential fall risk by concentrating more attentional resources towards maintaining stable posture, I suggest that the attentional resources remaining available for the awareness of potential fall threats within the environment become compromised. This uneven distribution of attentional resources may be caused by an underlying inflexibility of attentional prioritization amongst fall-fearful older adults. Future work is needed to determine whether the lack of prioritization flexibility is due to an inability, or lack of cooperation in adhering to instructions due to the fear of falling.

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