POSTURAL ANXIETY INFLUENCES THE ALLOCATION OF ATTENTIONAL RESOURCES AMONG YOUNGER AND OLDER ADULTS

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Dedication

This thesis is dedicated to my mom, Hayley and my dad, Darin. Thanks for always encouraging the importance of an education.

Abstract

The purpose of this thesis was to investigate the influence of postural anxiety on the capacity for Flexible Resource Allocation (FRA) among younger (YA) and older adults (OA). Two experiments were conducted to explore (a) the influence of heightened postural anxiety on the flexible allocation of attention among OA and (b) the influence of concurrent postural challenge and postural anxiety on FRA among YA. Participants performed a postural task concurrently to a cognitive task according to three instructional sets directing task priority. Experiment one revealed that FRA was compromised among OA during circumstances of heightened anxiety. This capacity however, remained available among YA. Therefore, for the second experiment I varied the support surface to explore whether the capacity for FRA could be sustained when posture was challenged beyond static stance. Results indicated that YA altered cognitive task performance according to instructional set without compromising postural stability. These findings suggest that even when posture is challenged during heightened postural anxiety, YA maintain the capacity to automatically allocate attention to a postural task while performing a secondary task. Conversely, it seems that heightened postural anxiety strengthens the attentional bias to posture and subsequently compromises FRA among OA. Overall, results from this thesis suggest that the capacity for FRA is age and situation dependent.

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Chapter 1: General Introduction

One third of older adults (OA) over 65 years of age fall each year (Rubenstein, 2006). This fall rate increases to nearly 50% by the age of 85 years (Iinattiniemi, Jokelainen, & Luukinen, 2009). Falls are the leading cause of hospitalization among the elderly (Wilkins, 1999), and often result in bone fractures, soft tissue injury, joint dislocation and increased morbidity (Tinetti, Speechley, & Ginter, 1988). In fact, approximately 1% of deaths among elderly Canadians are attributed to falls. Although the acute physical effects of a fall episode are concerning, additional longer term consequences also affect OA who fall. For example, activity avoidance, low self-efficacy, reduced self-confidence, functional decline, social withdrawal, depression, anxiety and fear of falling (FOF) are associated with falls in the elderly (Legters, 2002; Tinetti & Williams, 1998). Moreover, it is now realized that 11% of fallers began to receive formal health care or were placed in an institutional care facility following a fall (Wilkins, 1999). Institutionalization and hospitalization places a financial burden on the health care system in addition to reducing the independence of OA (Stevens, Corso, Finkelstein, & Miller, 2006).

There are numerous reasons why OA fall. To categorize these reasons, the causes of falling have been separated into intrinsic and extrinsic factors (Shumway-Cook, Baldwin, Polissar, & Gruber, 1997). Nearly 80% of falls occur within the home and can be attributed to extrinsic factors that stem from environmental contributors such as poor lighting, tripping and stair negotiation (Morley, 2007; Tinetti, et al., 1988). Alternatively, intrinsic factors are those that represent an individual’s propensity to fall based on physiological and functional decline. Cognitive impairment, balance and mobility problems, and psychological changes (i.e., fear of falling, depression, anxiety) are examples of intrinsic factors associated with falling (Campbell, Borrie, & Spears, 1989; Rubenstein, Josephson, & Osterweil, 1996; Studenski, et al., 1994; van Schoor, Smit, Pluijm, Jonker, & Lips, 2002).

Of these psychological changes, FOF is the most widely recognized, with reports indicating FOF to persist in more than half of community dwelling OA, including those who have not experienced a fall (Brouwer, Musselman, & Culham, 2004). Fear of falling is defined as “a lasting concern about falling that leads to an individual avoiding activities they remain capable of performing” (Tinetti & Powell, 1993). This lasting concern about falling is associated with adverse wellness outcomes such as decreased social contact, reduced quality of life and activities of daily living, depression, reduced participation and confidence during physical activity, and higher rates of falling (Boyd & Stevens, 2009; Delbaere, Crombez, Vanderstraeten, Willems, & Cambier, 2004; Maki, Holliday, & Topper, 1991; Scheffer, Schuurmans, van Dijk, van der Hooft, & de Rooij, 2008).

The association between FOF and high fall rates has provided foundation for a dedicated line of research that explores the cognitive and motoric consequences associated with FOF. One avenue of study in this research area is predicated on the assumption that those who fear falling experience unique perceptual states and emotional responses regarding the possibility of experiencing a fall, and that these concerns can penetrate the motor and cognitive contributions that underlie the regulation of balance. In accordance with this line of inquiry, the purpose of my thesis was to explore whether anxiety about balance influences the management of attentional resources pertinent to postural control. This thesis is organized into a review of literature section that provides a relevant background of postural control and falling. The literature review provides a review of the current state of research for topics pertinent to FOF and the attentional contributions relevant for postural control. Following the review of literature are two experimental sections that explore the influence of heightened postural anxiety on flexible resource allocation among OA (Experiment 1) and the concurrent influence of postural challenge and postural anxiety on flexible resource allocation among younger adults (Experiment 2). The final general discussion section integrates the outcomes from both experimental reports and provides an interpretation of how the study outcomes correspond to and supplement current research perspectives.

1.1. Postural Control

1.1.1. Sensorimotor contributions to postural control. Postural control is a complex sensorimotor process that is dependent upon cognitive contributions (Lui-Ambrose, Khan, Eng, Lord, & McKay, 2004; Malouin, Richards, Jackson, Dumas, & Doyon, 2003; Woollacott & Shumway-Cook, 2002; Yogev-Seligmann, Hausdorff, & Giladi, 2008), and is defined as the regulation of motor output by the central nervous system (CNS) to maintain the dynamic relationship between the center of mass of the body (COM) and the base of support (BOS), as circumscribed by the feet (Maki & McIlroy, 1999; Pai & Patton, 1997). The Inverted Pendulum Model (Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998) provides a theoretical basis for postural control mechanics. In this model, the pendulum mass represents our COM, with the pivot point located at the ankle joints. Deviations of our COM within our BOS occur as we overcome the destabilizing effect of gravity. The pendulum pivots in the anterior-posterior and medial-lateral directions about the ankle joints to produce natural movement of the COM known as spontaneous postural sway (Winter, 1995). Principles of biomechanics dictate that the COM must remain within the limits of stability, as defined by a cone shaped perimeter extending up from the BOS, otherwise a fall or compensatory response must ensue (Horak, 2006; McCollum & Leen, 1989).

The motor outputs that regulate upright posture occur in response to sensory feedback regarding the present state of stability. These sources of feedback are pertinent for postural control and are provided by the vestibular, visual, and somatosensory systems. The vestibular system provides the CNS with a frame of reference regarding position and movement of the head with respect to gravity. Vision supplies a reference of verticality by providing information about head position and movement with respect to the environment. The somatosensory system indicates the position and motion of the body with respect to support surfaces and body segments. Feedback from each sensory system is integrated and reweighted by the CNS to ensure that the appropriate postural adjustments are implemented (Oie, Kiemel, & Jeka, 2002). We can infer the sensory contribution to postural control by manipulating sensory feedback and quantifying the motor responses that result.

A typical manipulation of sensory feedback from the vestibular, visual and somatosensory systems involves perturbing either the support surface or the visual environment and the removal of vision. In these scenarios, the support surface or visual environment rotates in direct opposition to participant spontaneous sway. As a consequence, the participant is subjected to inaccurate sensory feedback from the somatosensory and visual systems resulting in greater reliance on vestibular feedback to maintain postural stability.

In the laboratory, postural control is most readily assessed using two measurement techniques. Motion analysis systems provide a method to quantify the dynamics of COM movement while force platforms are used to capture the dynamics of the vertical ground reaction force (GRF) vector during upright standing. Displacement of the COM during spontaneous sway changes the movement and direction of the GRF vector. The center of pressure (COP), as derived from the GRF vector, maps the dynamics of the vertical GRF vector during postural sway. The deviations in the location of the COP within the BOS can be quantified to provide numerous indices of postural control including sway path length in the anterior-posterior and medial-lateral direction, frequency of sway, magnitude of sway, and the area of sway (Goldie, Bach, & Evans, 1989; Lafond, Corriveau, Hebert, & Prince, 2004). Sway path length indicates the total COP excursions occurring over time. Moreover, sway frequency and sway magnitude are components of sway path length used to characterize the temporal and spatial dynamics of COP excursions. As a whole, elliptical sway area provides a composite measure of postural control that accounts for the spatial dynamics of postural sway in the anterior-posterior and medial-lateral directions. The area of the ellipse that encompasses the COP excursions is used to infer the extent of postural control where a smaller sway area represents greater control of posture and a larger sway area represents reduced balance control.

1.1.2 Aging and postural control. Aging significantly affects musculoskeletal, sensory, and nervous system functioning essential for maintaining postural stability (Maki & McIlroy, 1996). Muscle mass and strength decrease 30-50% between the ages of 30-80 years (Aniansson, Grimby, & Hedberg, 1992; Frischknecht, 1998). This is concerning because lower extremity weakness and advanced age have been reported as risk factors for falling (Bergland, Jarnlo, & Laake, 2003; Campbell, et al., 1989; Luukinen, Koski, Laippala, & Kivela, 1995). Decreased flexibility, limited joint range of motion and reduced muscle power are related to normal upright posture becoming stooped (Brocklehurst, Robertson, & James-Groom, 1982b). Stooped posture affects the COM location and subsequently influences the control of spontaneous postural sway. In fact, spontaneous postural sway has been suggested to increase 10% with each decade of life (Gagey, Toupet & Heuschen, 1992) and is characterized by COM excursions within the BOS that occur more frequently and with greater amplitude and velocity (Baloh, Spain, Socotch, Jacobson, & Bell, 1995; Patla, Frank, & Winter, 1992). Lower extremity weakness, and reduced muscle power and torque in the lower limbs slow postural responses and are considered to contribute to increased postural sway known to occur with aging (Alexander, 1994). Moreover, reduced muscle activation (Patla, et al., 1992) and altered sequencing of muscle activation patterns have been observed among OA during quiet stance and following a perturbation to upright standing (Alexander, 1994; Woollacott, Shumway-Cook, & Nashner, 1986). Incorrect muscle activation can adversely affect the speed and accuracy of postural responses, resulting in instability and increasing the possibility of a fall (Alexander, 1994).

Changes in sensory acuity originate from weakened cutaneous sensitivity (Brocklehurst, Robertson, & James-Groom, 1982a; Kenshalo, 1986), decreased visual acuity, depth perception, contrast sensitivity, focusing ability (Horak, 2006), and deterioration within the vestibular system (Matheson, Darlington, & Smith, 1999). Declines in sensory acuity directly influence the maintenance of postural stability as demonstrated by increased postural sway when visual (Dijkstra, Schoner, & Gielen, 1994), vestibular (Day, Severac Cauquil, Bartolomei, Pastor, & Lyon, 1997; Johansson, Magnusson, & Fransson, 1995), and somatosensory (Jeka, Oie, & Kiemel, 2000; Jeka, Schoner, Dijkstra, Ribeiro, & Lackner, 1997; Kavounoudias, Gilhodes, Roll, & Roll, 1999) feedback is reduced. The integration of visual, vestibular and somatosensory feedback, occurring within the central nervous system, is suggested to be slowed among OA (Jeka, Oie, & Kiemel, 2008). The age dependent changes in sensory system acuity and central integration of the sensory systems responsible for the control of posture compromise postural control and are regarded to provide a primary reason for increased fall rates among the elderly (Horak, 2006; Lord, Clark, & Webster, 1991; Peterka & Loughlin, 2004).

1.2 Cognitive Contribution to Postural Control

1.2.1 Attention and executive function. Executive function is a higher level of cognitive functioning responsible for the modulation and regulation of behaviour (Royall, et al., 2002) whereas attention is the capacity for information processing (Woollacott & Shumway-Cook, 2002) that is controlled by executive processes (Badgaiyan, 2000). Foundation perspectives considered the regulation of posture and locomotion to be automatic tasks achieved through activation of the motor system by sensory stimuli and without need for higher cognitive resources. It is now firmly established that motot regulation of movement and higher cognitive function share similar neural networks (Badgaiyan, 2000; Sheridan & Hausdorff, 2007). Moreover, extensive evidence from dual task studies has confirmed a functional link between cognition and motor regulation of posture and locomotion (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Kerr, Condon, & McDonald, 1985; Lajoie, Teasdale, Bard, & Fleury, 1993; Stelmach, Zelaznik, & Lowe, 1990; Teasdale, Bard, LaRue, & Fleury, 1993; Teasdale, Stelmach, Breunig, & Meeuwsen, 1991). Thus, it is now confirmed that posture requires attentional resources. As a consequence concurrent performance of a cognitive and postural task provides opportunity for competition of attentional resources and the potential for dual task interference.

1.2.2 Dual task theory and application pertinent to posture and gait. There are several attentional theories explaining dual task interference. Capacity sharing models speculate that tasks are performed in parallel and that processing capacity is finite (Kahneman, 1973; Yogev-Seligmann, et al., 2008). As such, dual task decrements may occur for both tasks if processing capacity is exceeded. Alternatively, self-prioritization of one task may occur, consequently compromising performance of the other task (Kahneman, 1973; Yogev-Seligmann, et al., 2008). The Bottleneck theory suggests that simultaneous performance of two tasks requiring similar neural networks will create a bottleneck in processing order. Once the bottleneck is formed, processing of the first task must be completed before processing of the second task can ensue (Pashler, 1994; Yogev-Seligmann, et al., 2008). For example, gait velocity may be reduced while performing a secondary task or secondary task performance may be delayed while gait velocity is maintained. The Multiple Resource Theory proposes that concurrent performance of two tasks may require the incorporation of multiple cognitive processing resources (Pashler, 1994). Dual task interference will not occur if the two tasks do not share common processing resources. However, if the two tasks require the same processing resources, then dual task interference will occur. For example, interference may not occur when performing a cognitive task while walking as the resources required for walking are dissimilar to those employed for successfully completing a cognitive task. However, performing an additional motor task that shares common processing resources with walking will result in dual task interference (Pashler, 1994).

Examining the performance differentials of the cognitive and postural task during simultaneous performance of the tasks provides insight into how concurrent tasks are managed by executive function. Comparing simultaneous performance of a posture and cognitive task to the respective single task performance provides an indication of the level of dual task interference. For example, compromised performance of a cognitive task may occur while simultaneously performing a postural task (Andersson, et al., 2002; Andersson, Yardley, & Luxon, 1998; Doumas, Rapp, & Krampe, 2009; Doumas, Smolders, & Krampe, 2008; Jamet, Deviterne, Gauchard, Vancon, & Perrin, 2007; Kerr, et al., 1985; Lajoie, et al., 1993; Maylor & Wing, 1996; Muller, Redfern, & Jennings, 2007; Teasdale, et al., 1993). Alternatively, reduced postural stability has been observed when introducing a secondary task (Doumas, et al., 2009; Doumas, et al., 2008; Jamet, et al., 2007; Melzer, Benjuya, & Kaplanski, 2001; Redfern, Jennings, Martin, & Furman, 2001). Nevertheless, according to the Capacity Sharing Theory the occurrence of dual task interference in both instances implies a lack of processing capacity rather than a bottleneck in processing. Moreover, interference of a postural task while concurrently performing a visuospatial cognitive task (Kerr, et al., 1985) implies that cognition and posture rely on similar functional resources, thus opposing the Multiple Resource Theory. For these reasons the Capacity Sharing Theory has been selected as the theoretical framework for my thesis research.

1.2.3 Attention and postural control.

The interdependence between the cognitive and motor systems for the regulation of postural control is now well established (Andersson, et al., 2002; Badgaiyan, 2000; Kerr, et al., 1985; Lajoie, Teasdale, Bard, & Fleury, 1996; Sheridan & Hausdorff, 2007; Stelmach, et al., 1990; Teasdale, et al., 1993; Teasdale, et al., 1991). Research contributions over a number of years have indicated that this relationship is affected by various factors including age (Brown, Sleik, Polych, & Gage, 2002; Jamet, et al., 2007; Lajoie, et al., 1996; Marsh & Geel, 2000), complexity of the cognitive (Jamet, et al., 2007; Kerr, et al., 1985), postural (Redfern, et al., 2001; Redfern, Muller, Jennings, & Furman, 2002) or locomotor tasks (Li, Lindenberger, Freund, & Baltes, 2001), the quality or access to sensory information, and affective influences (Brown, Sleik, et al., 2002; Liu-Ambrose, Katarynych, Ashe, Nagamatsu, & Hsu, 2009; Woollacott & Shumway-Cook, 2002). A confirmed finding is that OA dedicate more of their available attention to postural control than do YA (Doumas, et al., 2008; Jamet, et al., 2007; Marsh & Geel, 2000; Redfern, et al., 2001; Woollacott & Shumway-Cook, 2002). For example, YA maintained postural stability whereas OA experienced decrement of postural stability when performing cognitive and postural tasks simultaneously (Doumas, et al., 2008; Jamet, et al., 2007; Redfern, et al., 2001). This phenomenon provides foundation for the well substantiated effects of performing a cognitive task concurrent to a standing postural task.

Current perspective dictates that the concurrent performance of a postural and cognitive task may compromise the availability of attentional resources that can be allocated to postural control (Woollacott & Shumway-Cook, 2002) and subsequently increase the possibility of falling among OA (Marsh & Geel, 2000). Prioritizing postural stability by restricting the division of attentional resources is a possible strategy to avoid instability. In support of this possibility, OA adopt a “posture first” strategy in dual task scenarios. This strategy implies that available attentional resources are naturally prioritized toward postural control and locomotor task completion (Doumas, et al., 2008; Li, et al., 2001; Redfern, et al., 2002; Reelick, van Iersel, Kessels, & Rikkert, 2009). The “posture first” strategy proposes that the allocation of available attentional resources depends upon a centrally modulated hierarchy that considers task challenge, participant goals, and instructional set (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). When posture is sufficiently challenged, OA prioritize preserving balance over performing well on the secondary task (Doumas, et al., 2008; Redfern, et al., 2002). Conversely, when postural stability is not threatened or challenged, attention may be diverted from maintaining postural stability to performing well on the secondary task (Doumas, et al., 2008). For example, when posture was not challenged OA demonstrated a 40% reduction of postural stability to maintain accurate performance of the cognitive task. Conversely, when posture was challenged by sway referencing the support surface, OA maintained postural stability to a level similar to that observed during single task postural performance. This preservation of postural control however, was accompanied by a 15% reduction of cognitive task performance (Doumas, et al., 2008).

In a similar way, imposing a threat to postural control by increasing the consequences of instability also seems to influence priority for attentional allocation (Brown, Gage, Polych, Sleik, & Winder, 2002). Brown and colleagues (2002) used a prioritization index to determine how YA and OA prioritized attention in conditions of low and high postural threat (Brown, Sleik, et al., 2002). Similar to findings by Doumas and colleagues (2008), OA and YA maintained secondary task performance at the expense of postural control in a low threat condition. However, during conditions of postural threat, cognitive task performance diminished and postural stability improved among OA (Brown, Sleik, et al., 2002). These findings were interpreted to indicate a "posture first" strategy among OA, suggesting that the prioritization of attentional contributions to postural control is age and context dependent.

1.2.4 Flexible resource allocation and explicit prioritization.

Flexible Resource Allocation (FRA) is a management strategy for dual task scenarios whereby attentional resources are considered to be alternately allocated between concurrent tasks. Determining the capacity for FRA is achieved by imposing instructional sets that direct allocation of attention to a specific task. For instance, simultaneously performing a postural and cognitive task under 'posture-priority' instructions requires the participant to direct attention to the postural task while still completing the cognitive task. Similarly, completion of the same dual task under 'cognitive priority' instructions requires the participant to direct attention to performing the cognitive task while still maintaining postural or locomotor control.

Implementing explicit instructions to prioritize either the postural or cognitive task has indicated that YA can effectively allocate attention according to instructional set (Siu, Chou, Mayr, Donkelaar, & Woollacott, 2008). This interpretation is based on findings indicating that obstacle crossing gait velocity decreased during posture priority instructions compared to cognitive priority instructions. Similarly, cognitive task performance under cognitive priority instructions improved beyond that when provided with posture priority instructions (Mitra & Fraizer, 2004). In a recent study, explicit instructions were given to YA that specified prioritization of the postural task, the cognitive task, or setting equal priority to each task. The index of cognitive performance showed that YA improved cognitive performance during cognitive priority instructions compared to posture priority instructions. However, postural performance did not differ when provided with the posture priority instructional set. Based on these results it was interpreted that YA could flexibly allocate attention to the cognitive task. From the finding of no change in postural performance according to the posture priority instructional set it was forwarded that YA have the capacity to regulate the allocation of attentional resources to a secondary task and still have resources available to automatically prioritize postural stability (Siu & Woollacott, 2007).

Recent findings using explicit instructional sets have also indicated that the capacity for FRA is dependent upon age (Siu, et al., 2008; Yogev-Seligmann, et al., 2009), level of physical function (Siu, Chou, Mayr, van Donkelaar, & Woollacott, 2009), and postural challenge (Siu, et al., 2008; Siu, et al., 2009). When provided with explicit instructions for task priority, OA were able to flexibly allocate attention between a simultaneously performed gait and cognitive task (Siu, et al., 2008; Siu, et al., 2009; Yogev-Seligmann, et al., 2009). When instructed to prioritize the cognitive task during increased postural challenge, for example during obstacle negotiation, cognitive task performance improved. Similarly, when instructed to prioritize attention to crossing the obstacle, both groups demonstrated reduced obstacle crossing gait velocity (Siu, et al., 2008; Siu, et al., 2009). These results suggested that YA and OA are able to flexibly allocate attention. An age difference however, seemed to exist for the degree of flexible allocation, implying that OA may have reduced capacity for flexibly allocating attention in this scenario (Siu, et al., 2008).

Given the possibility that falling while dual tasking is associated with compromised ability to flexibly allocate attention between concurrent tasks (Lajoie, et al., 1993; Shumway-Cook & Woollacott, 2000; Shumway-Cook, Woollacott, et al., 1997; Siu, et al., 2008), Siu and colleagues (2009) investigated the ability to flexibly allocate attention among balance impaired OA (Siu, et al., 2009). Results indicated that postural and cognitive performance did not change despite set priority instructions. This finding was interpreted to indicate that balance impaired OA did not flexibly allocate attention between a simultaneously performed gait and cognitive task (Siu, et al., 2009). These findings also imply that balance impaired OA may have a reduced repertoire of attentional management strategies relevant for posture and gait dual tasks. Moreover, this deficit furthers the possibility that compromised FRA may contribute to balance constraints among balance impaired OA (Siu, et al., 2009). One hypothesis proposes that compromised ability to flexibly allocate attention between a cognitive and postural task may result from deficient executive processes relating to the ability to comply with instructional sets (Mayr, 2001). Exploration of this hypothesis required healthy and balance impaired OA to perform a cognitive and walking task concurrently according to three instructional sets. Findings indicated that the ability to flexibly allocate attention was compromised among balance impaired OA as evidenced by no change in postural or cognitive performance according to instructional set (Siu, et al., 2009). Investigation of the relationship between executive function and the index of FRA indicated no significant relationship (Siu, et al., 2009). Therefore, Siu and colleagues (2009) postulated that compromised ability to flexibly allocate attention was unrelated to executive function. Rather, compromised ability to flexibly allocate attention was suggested to be associated with factors relating to balance (Siu, et al., 2009).

1.3 Affective Contributions to Postural Control

1.3.1 Fear of falling and associated emotional states. Fear of falling (FOF) is "a lasting concern about falling that leads to an individual avoiding activities they remain capable of performing" (Tinetti & Powell, 1993). Fear of falling has been reported by OA with and without a history of falls (Friedman, Munoz, West, Rubin, & Fried, 2002), and is now considered to be a predictor of falls among OA (Friedman, et al., 2002; Hadjistavropoulos, et al., 2007). Currently, fall fearfulness is assessed using self-efficacy measures, self-report scales and activity-related measures. The Activities-specific Balance Confidence scale (ABC) rates the ability to perform ADL while maintaining balance and remaining steady (Powell & Myers, 1995). The Falls Efficacy Scale (FES) rates perceived self-efficacy at avoiding falls while performing specific activities of daily living (Tinetti, Richman, & Powell, 1990). Compared to the FES, the ABC provides a wider range of activity difficulty and a more detailed description of the activity being rated (Scheffer, et al., 2008). Conversely, the Survey of Activities and Fear of Falling in the Elderly (SAFFE) involves rating concern about falling and activity restriction (Lachman, et al., 1998). Reliabilities of the ABC, FES, and SAFFE range from good to excellent (Jorstad, Hauer, Becker, Lamb, & ProFa, 2005; Scheffer, et al., 2008). Overall and activity specific FOF is also assessed using questions requiring a dichotomous 'yes' or 'no' response (Scheffer, et al., 2008).

Early research by Maki et al. (1991) examined the relationship between postural control and FOF among fall fearful and non-fearful OA (Maki, et al., 1991). Fall fearful OA differed from non-fearful OA across a number of indices of postural control but only when standing with eyes closed. Maki and colleagues (1991) suggested that levels of postural stability were similar for both groups and that the reduced postural control with eyes closed may result from underlying anxiety regarding the risk of falling (Maki, et al., 1991). Current research examining the influence of FOF on postural control and gait has provided further insight regarding the relationship between postural control and fall relevant fear. For example, fall fearful OA have a reduced capacity at achieving maximal COP excursions within the BOS when leaning towards the limits of stability (Binda, Culham, & Brouwer, 2003). Fall fearful OA also demonstrate a more cautious gait pattern, characterized by slower gait speed, shorter stride length, increased stride frequency and longer double limb support time compared to their non-fearful counterparts (Chamberlin, Fulwider, Sanders, & Medeiros, 2005; Delbaere, Sturnieks, Crombez, & Lord, 2009; Reelick, et al., 2009).

To further examine how perceptual and emotional states influence motor and cognitive contributions relevant to postural control, experimental paradigms have been used that mimic the experience of fall fearful OA. The most prominent experimental paradigm, employed for more than a decade, is the surface height model (Brown & Frank, 1997). In this model, the height of the support surface is changed between testing conditions to provide environmental contexts that differ in the consequences for instability, should a fall occur (Adkin, Campbell, Chua, & Carpenter, 2008; Adkin, Frank, Carpenter, & Peysar, 2000, 2002; Brown & Frank, 1997; Brown, Gage, et al., 2002; Carpenter, Frank, & Silcher, 1999; Carpenter, Frank, Silcher, & Peysar, 2001; Davis, Campbell, Adkin, & Carpenter, 2009; Delbaere, et al., 2009; Gage, Sleik, Polych, McKenzie, & Brown, 2003; Huffman, Horslen, Carpenter, & Adkin, 2009; Lamarche, Shaw, Gammage, & Adkin, 2009). In this paradigm participants stand at the edge of a platform or walk along a walkway positioned at heights ranging from ground level to, in the most extreme reported case, 3.2 meters above ground (Adkin, et al., 2008; Adkin, et al., 2000; Brown, Doan, McKenzie, & Cooper, 2006; Brown & Frank, 1997; Brown, Gage, et al., 2002; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001; Davis, et al., 2009; Delbaere, et al., 2009; Lamarche, et al., 2009). The surface height model has been shown to influence psychological indices of arousal (Adkin, et al., 2002; Brown, Polych, & Doan, 2006; Brown, Sleik, et al., 2002; Carpenter, Adkin, Brawley, & Frank, 2006; Carpenter, et al., 1999; Carpenter, et al., 2001), anxiety (Adkin, et al., 2002), and balance confidence (Adkin, et al., 2002; Carpenter, et al., 2006) as well as numerous indices of postural control (Adkin, et al., 2000, 2002; Brown & Frank, 1997; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001). Findings to date indicate that the postural adaptations when standing at the edge of an elevated platform include a backward lean, characterized by a posterior shift of center of pressure position, and a tighter regulation of the COM characterized by increased frequency and reduced amplitude of sway (Adkin, et al., 2000; Brown, Polych, et al., 2006; Carpenter, et al., 1999; Carpenter, et al., 2001). Moreover, locomotor adaptations are characterized by increased double limb support time and reduced gait velocity, stride length and cadence (Brown, Gage, et al., 2002; Delbaere, et al., 2009).

These gait and postural adaptations are suggested to serve as a protective mechanism for the control of posture and gait (Brown, Polych, et al., 2006).

More recently, Davis and colleagues (2009) used an extreme platform surface height (3.2 meters) to compare the postural characteristics of YA according to the presence of an imposed fear of falling. Participants performed a static standing task at the edge of the platform and were categorized as fall fearful or non-fall fearful based on subjective ratings for fall fearfulness. Indices of postural control for non-fall fearful YA, characterized by increased sway frequency and reduced sway amplitude, were similar to those demonstrated in previous studies employing the surface height model (Adkin, et al., 2000; Brown, Polych, et al., 2006; Carpenter, et al., 1999; Carpenter, et al., 2001). Conversely, the postural control strategies of fall fearful YA, characterized by an increased sway frequency and sway amplitude, were similar to fall fearful OA at ground level (Maki, et al., 1991). This was the first study to observe postural characteristics of fall fearful OA among younger cohorts using the surface height model, providing further support for the use of the surface height model to mimic fall fearful postural adaptations.

1.4 Summary

Falling is a significant concern among the elderly that is associated with the physiological and biomechanical consequences of aging, as well as the psychological contribution of balance confidence, postural anxiety and attention. Fear of falling and falling co-exist in many OA, a matter that has been shown to adversely affect the lives of OA. A well established fact is that posture and gait require attentional resources. Various management strategies, including division of attentional resources and FRA are available to direct the allocation of attentional resources. Although FRA is recognized as an effective strategy to manage dual task scenarios (Mitra & Fraizer, 2004; Shumway-Cook & Woollacott, 2000; Siu, et al., 2008; Siu, et al., 2009; Siu & Woollacott, 2007; Woollacott & Shumway-Cook, 2002), to the best of my knowledge, the influence of psychological factors, such as postural anxiety, on this attentional management strategy has received little or no consideration. From the documented evidence that anxiety, balance confidence, and fear of falling have been shown to influence the attentional requirements of postural control, it is possible that psychological factors related to postural control may also influence attentional strategies relevant for postural control. Aligned with this possibility, the purpose of this thesis was to investigate the influence of postural anxiety on the ability to flexibly allocate attention among YA and OA.

My research question is framed within the prevailing theory that postural anxiety alters cognitive contributions for postural control (Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002). I hypothesize that the capacity for FRA will be compromised when postural anxiety is heightened. This hypothesis is based on previous findings from our laboratory indicating that the natural bias of attentional resources toward postural control that underlies the 'posture first' phenomenon is strengthened when postural anxiety is heightened (Brown, Gage, et al., 2002; Brown, Sleik, et al., 2002). My expectation is that compromised FRA is a subsequent outcome of the shift in attentional dynamics associated with heightened postural anxiety. As such, I expect that despite directed instructional sets, the reciprocity between performance of a postural and cognitive task that defines FRA will be weakened when postural anxiety is heightened. Consequently, performance of the postural task will improve while cognitive task performance will diminish.

Chapter 2: Objective of Thesis

2.1 Experiment 1: Heightened Postural Anxiety Influences Flexible Resource Allocation among Older Adults.

2.1.1 Objective. The objective of Experiment 1 was to examine the influence of postural anxiety on FRA among healthy younger and older adults.

2.1.2 Hypothesis. In accordance with the findings that healthy OA can flexibly allocate attention while walking (Siu, et al., 2009), and that OA prioritize posture while dual tasking in contexts of postural anxiety (Brown, Sleik, et al., 2002), I hypothesized that the capacity for FRA would be compromised among OA but not YA when postural anxiety was heightened. Specifically, in the absence of postural anxiety, I expected that both YA and OA would flexibly allocate attention by regulating postural stability and cognitive performance according to the instructional sets. During circumstances of heightened postural anxiety YA would maintain the capacity for FRA. Conversely, OA would implement the posture first strategy, characterized by increased postural stability and reduced cognitive performance, regardless of instructional set.

2.2 Experiment 2: The Influence of Concurrent Postural Challenge and Postural Anxiety on Flexible Resource Allocation among Younger Adults.

2.2.1 Objective. The objective of Experiment 2 was to investigate the effect of concurrent postural challenge and anxiety on the FRA of YA.

2.2.2 Hypothesis. Based on the known influence of postural challenge and postural anxiety on postural control among YA and OA (Brown, Sleik, et al., 2002; Davis, et al., 2009; Doumas, et al., 2008) I hypothesized that concurrent postural challenge and postural anxiety would impose a state of extreme postural anxiety among

YA that would compromise FRA. Specifically, I predicted that the capacity for FRA would remain in conditions of postural challenge and postural threat. However, when postural challenge and anxiety were imposed concurrently, YA would prioritize postural control by increasing postural stability, resulting in a decrease of secondary task performance.

Chapter 3: Experiment 1 – Heightened postural anxiety influences flexible resource allocation among older adults

3.1 Abstract

One management strategy for dual task scenarios is to alternately switch attention between tasks, a strategy known as Flexible Resource Allocation (FRA). Recent research has indicated compromised FRA among fall-fearful older adults, an observation that may be explained by an underlying anxiety regarding postural control. To assess FRA, YA and OA performed a cognitive task concurrent to a postural task at two surface heights known to alter postural anxiety. To assess FRA, three task priority instructional sets were employed. Elliptical sway area (ESA) and verbal reaction time (VRT) were acquired from ground reaction forces and verbal responses. Results indicated that regardless of surface height, YA altered cognitive and postural performance in accordance to instructional sets. Conversely, OA did not alter postural or cognitive performance according to instructional set in the HI condition. It seems then that the capacity for FRA is compromised among OA in situational contexts known to heighten postural anxiety, suggesting that FRA is situation-dependent.

3.2 Introduction

Goal-directed actions, including postural control and gait, require executive function and attention (Badgaiyan, 2000; Sheridan & Hausdorff, 2007). In the requirements of daily life however, standing and walking are often paired with an additional task, further increasing the demands for executive function and attention. For example, walking while talking requires that attention be dually provided towards maintaining steady state locomotion and engaging in a conversation. The cognitive strategies considered to manage such multitask scenarios include set switching of attention and the division of attention between tasks. Divided attention parses available resources between tasks, while set switching of attention is a strategy that alternately directs attention between tasks that are performed concurrently. Regardless of the attentional strategy however, the Limited Capacity Theory (Kahneman, 1973) dictates that a performance decrement for one or both tasks will occur if the attentional demand of a multitask scenario exceeds attentional resource availability. One advantage of the set-switching strategy that supersedes the divided attention strategy is that the alternate allocation of attentional resources between both tasks potentially allows concurrent task performance without evidenced detriment.

In multitask scenarios that include standing or walking it appears that there is a natural and unconscious bias of attentional resources to the balance or gait task (Bloem, Grimbergen, van Dijk, & Munneke, 2006; Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001; Brauer, Woollacott, & Shumway-Cook, 2001; Brown, Sleik, et al., 2002; Li, et al., 2001; Muller, et al., 2007; Rapp, Krampe, & Baltes, 2006; Shumway-Cook, Woollacott, et al., 1997; Yogev-Seligmann, et al., 2008). This apparent prioritization has become known as the ‘posture first’ strategy and is dependent upon task characteristics, participant objectives, and instructional set (Shumway-Cook, Woollacott, et al., 1997; Woollacott & Shumway-Cook, 2002) While the prioritization of postural control may serve as a protective strategy by optimizing attentional allocation for balance at the expense of a secondary task, this strategy may inadvertently jeopardize stability if attentional resources are not available to attend to external threats and challenges. The flexible allocation of attention between a postural and cognitive task may be a viable strategy to manage multitask scenarios by allowing the identification of such hazards to postural stability.

Current research in our laboratory focuses on understanding how postural anxiety may influence the attentional contributions to postural control. Our most recent findings have confirmed a compromised capacity for FRA among fall fearful OA in dual task scenarios (White, 2009) that is compounded by the inability to disengage attention when balance threatening stimuli are presented (Brown, White, Doan, Sessford, in press). One theory, grounded in the documented effect of postural anxiety on the attentional contributions to posture and locomotor control (Brown, Doan, et al., 2006; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002), is that an underlying anxiety about falling among OA who fear falling strengthens the bias of attention toward postural control and subsequently compromises the capacity for FRA. To test this outcome, the purpose of this paper was to determine the effect of postural anxiety on FRA. Postural anxiety was imposed in accordance with the postural threat paradigm by increasing the height of the support platform. Both younger and older adults were included in this study to assess the potential changes due to aging. Based on previous findings (Siu, et al., 2009; Yogev-Seligmann, et al., 2009) I hypothesized that in the absence of postural anxiety, both YA and OA would demonstrate flexible allocation of attention. In circumstances of postural anxiety YA would remain able to flexibly allocate attention however, this ability among OA would become compromised. The predicted age difference was based on previous findings demonstrating that contexts of increased postural anxiety did not influence cognitive task performance among YA (Brown, Sleik, et al., 2002).

3.3 Methods

3.3.1 Participants. Fifteen YA (age, 22.53 ± 2.42 years) and 16 OA (age, 68.68 ± 4.74 years) participated in this study. Younger adults were recruited from the University of Lethbridge student body and OA were recruited from within the community. All participants were free of neurological and orthopaedic pathology that may have adversely affected their ability to comply with the experimental procedures. Ethical approval was provided by the Human Research Ethics Committee of the University of Lethbridge prior to subject recruitment. Voluntary informed consent was provided by each participant preceding any experimental procedure. Older adult participants completed the Mini-Mental Status Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) and the Activities-Specific Balance Confidence (ABC) (Powell & Myers, 1995) questionnaire to evaluate cognitive function and balance confidence, respectively.

3.3.2 Protocol. Participants performed a postural and cognitive task concurrently across two conditions of postural threat and three instructional sets. The postural task required participants to stand as still as possible with arms positioned at their side and feet together and with toes aligned on the leading edge of the force platform (Bertec Corporation, Columbus, OH). The force platform was embedded at the edge of a larger platform positioned on a hydraulic lift (1.2 × 1.8 m; Pentalift, Guelph, ON) used to manipulate platform surface height. The cognitive task was a Spatial Memory Task (SMT) consisting of a series of visual sequences within a 5x4 grid that were presented on a computer monitor (White, 2009; Figure 3.1a and 3.1b). The cognitive task required participants to remember a pattern of squares presented within the grid, the difficulty of which could be altered by increasing the number of squares used to create the pattern within the grid. Further detail of the cognitive task is provided in Section 3.3.3. The platform surface heights used were ground level (Low Threat; LO) and 1.4 meters above ground level (High Threat; HI). Surface height was counterbalanced so half the participants started in the LO threat condition and the other half started in the HI threat condition. Instructional sets differed by priority for attentional allocation as follows:

No priority (NP) – No instruction provided.

Posture priority (PP) – Focus your attention on your posture so that you stand as still as possible while still completing the cognitive task.

Cognitive priority (CP) – Focus your attention on the cognitive task so that you respond as quickly and accurately while still maintaining your balance.

Instructional sets were block randomized so that three consecutive trials were performed according to a single instruction. Each instructional set was repeated prior to trial commencement to ensure consistency across all trials. The purpose of the NP instruction was to provide an indication of natural, unbiased task prioritization. Therefore, PP and CP trials were performed subsequent to completion of the NP trials to avoid introducing bias due to instructional set. Three trials of 30 second duration were performed for each instructional set in each threat condition for a total of 18 trials.

Participants were equipped with a whole-body harness secured to a support beam on the ceiling and were spotted by a research assistant at all times. Participants were provided opportunity for familiarization with the SMT prior to testing commencement. This session also served as an opportunity to individually titrate task difficulty and standardize attentional load between subjects (Doumas, et al., 2008). The criterion for titration of task difficulty required participants to perform the SMT beginning with the easiest challenge using three squares. The challenge increased in subsequent trials by adding a square until a maximum of 6 squares could be performed with an accuracy rate above 80% (Brown and White, in progress). If accuracy fell below 80%, the number of squares in which 80% accuracy was previously achieved was used. All familiarization and titration trials were performed while seated. Once the level of task difficulty was established, each participant then performed three seated trials at the titrated level of challenge. The results of these collections provided data for a baseline measure of cognitive performance. Participants then stood on the platform and performed the SMT according to the instructional sets. Upon completion of the testing block in each height condition, participants rated their fall anxiety and balance confidence using a likert scale that provided ratings of fall anxiety using a scale of 0% (not anxious at all) to 100% (extremely anxious). Participants were then asked to rate their confidence in their ability to maintain their balance during the testing block using a scale of 0% (not confident at all) to 100% (extremely confident) (Huffman, et al., 2009).

3.3.3 Cognitive task. The SMT was a four stage visual sequence that required 10 seconds to complete. Trial onset began with the presentation of a blank 5x4 grid from time 0 to 1000 milliseconds. A visual load consisting of the titrated number of filled squares was then presented in the 5x4 grid from time 1000 to 4000 milliseconds. Participants were required to remember the position of the squares comprising the visual load. Following this presentation, a blank grid appeared from time 4000 to 8000 milliseconds. The task concluded with the appearance of two probe squares from time 8000 to 10000 milliseconds. One probe square was positioned congruent to the position of one of the filled squares whereas the other was positioned incongruent to all the filled squares. Participants were instructed to respond by reciting the digit located within the probe square that was positioned congruently to one of the filled squares. This sequence of presentations repeated three times for each trial.

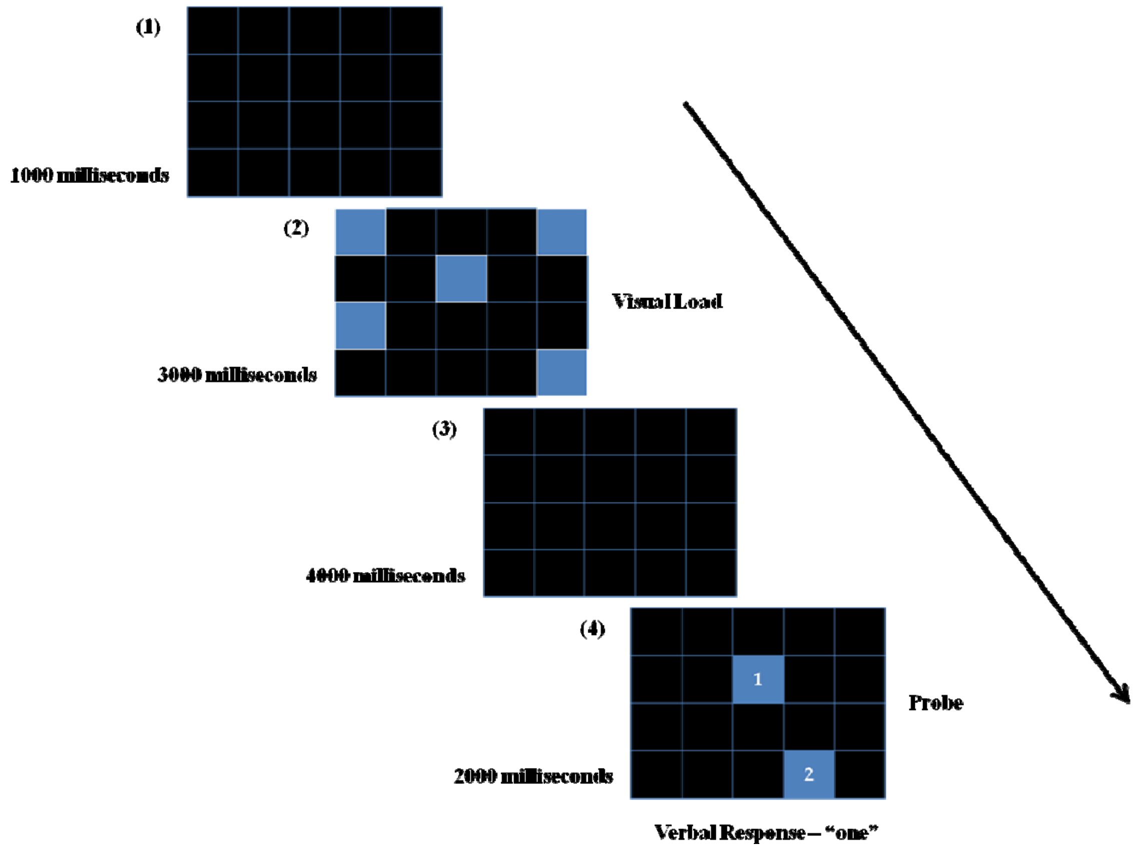

Figure 3.1a The SMT began with blank 5x4 grid for 1000 milliseconds (1), followed by the presentation of a visual load for 3000 milliseconds (2). Participants were required to remember the position of the filled squares viewed during the visual load. Subsequent to the visual load, a blank grid was presented for 4000 milliseconds (3). To conclude the SMT, two probe squares were presented for 2000 milliseconds (4). One square was positioned coincident to a filled square presented in the visual load and one positioned incoincident to all filled squares. Therefore, the correct response for this trial would be '1'.

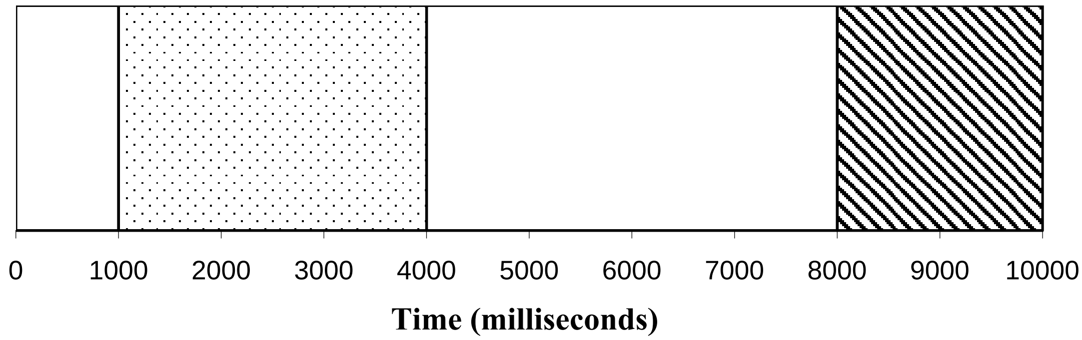

Figure 3.1b The temporal sequence of the SMT began with the presentation of a blank grid (first white bar) after which, a visual load was provided (spotted bar). The visual load was subsequently removed and a blank grid was presented again (second white bar). The task concluded with the presentation of two response squares (hatched bar).

3.3.4 Instrumentation and data processing. Separate forceplates and platform surrounds were used for each testing condition. One forceplate was fixed within the platform surround positioned in the LO threat condition while the other forceplate was fixed within the platform surround located in the HI threat condition. The SMT was created using graphical interface experimental design software (E-Prime 2.0). The SMT program emitted two auditory signals used to identify (1) trial initiation and (2) probe square onset (Figure 3.2). Verbal responses for the SMT task were acquired using a head-mounted microphone. Galvanic skin conductance was collected using two silver/silver chloride electrodes connected to a BioDerm Skin conductance Level Meter (UFI, Morro Bay, CA). The electrodes were fastened to the middle phalange of the second and third digits for the duration of the testing. All signals were sampled through an analog to digital interface unit using Vicon Motus (Peak Performance Technologies and Vicon Motus 9.0 software, Englewood, CO, USA) at a frequency of 600 Hz. Ground reaction forces and moments acquired from the forceplate were filtered using a dual pass fourth order Butterworth filter with a cutoff frequency of 5 Hz. Center of pressure (COP) location in the anterior-posterior and medial-lateral directions was calculated from ground reaction and moment forces acquired in the three orthogonal axes. Data points used to determine GSC responses as well as the index of cognitive performance were acquired from the raw unfiltered analog signals.

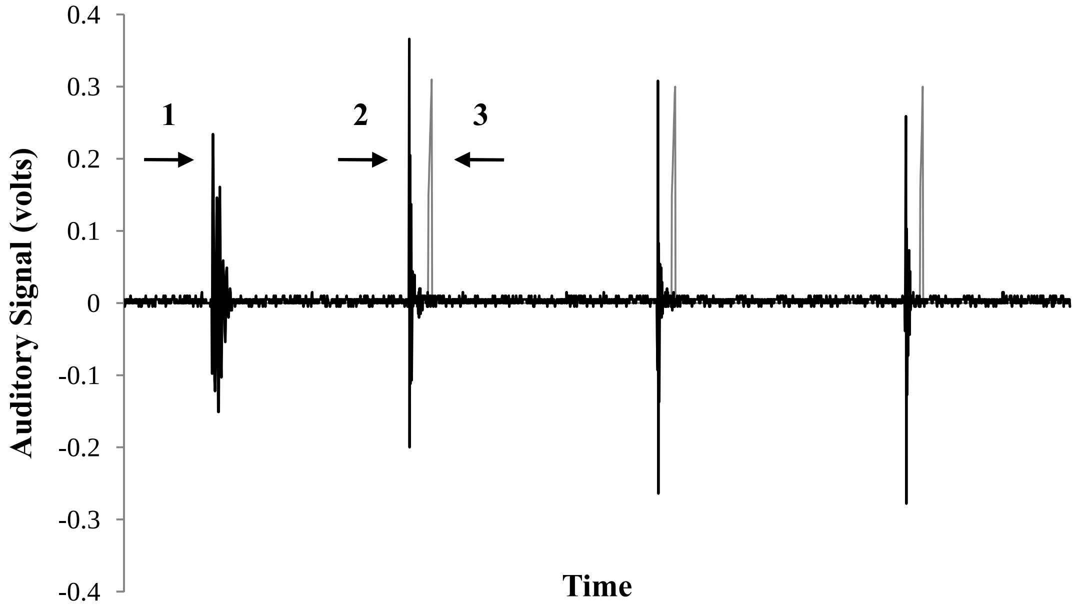

Figure 3.2 Two different auditory signals were used to identify trial initiation and probe square onset. Trials began with an auditory signal (1) that indicated trial initiation and the presentation sequences of the SMT. A second auditory signal (2) was used to indicate the appearance of a probe square. Following this the participant responded by verbalizing their response (3).

3.3.5 Measures of interest. Elliptical Sway Area (ESA) was selected as the index to quantify postural control and verbal reaction time (VRT) was chosen as the index for cognitive performance. Both these measures were calculated using custom written algorithms (MATLAB, Version R2009a; The Mathworks, Natick, MA, USA). A modified version of the Attentional Allocation Index (AAI) (Siu & Woollacott, 2007) was used to provide an index of FRA. Elliptical sway area of COP displacement was calculated using a 95% confidence interval in which the ellipse encompasses 95% of the COP trajectories. The ESA calculations were based on the principal components analysis method where the ellipse is determined by using the eigenvalues of the covariance matrix between the anterior-posterior and medial-lateral COP trajectories. Verbal reaction time was defined as the latency from response stimulus probe onset to the verbal response. These indices of postural and cognitive performance were used to calculate scores for the Attentional Allocation Index. In the present study the AAI was modified (mAAI) from the algorithm originated by Sui & Woollacott (2007) to align positive score values with the specified instructional set and to incorporate the NP instructional set which produced an index score relative to self-selected task priority (Siu & Woollacott, 2007). Modified attentional allocation index values for postural control and cognitive performance were determined using the following calculations:

m-AAI for posture = [(CP-PP)/NP] x 100

m-AAI for cognition = [(PP-CP)/NP] x 100

Accuracy for verbal responses of probe location was determined by comparing the documented responses to the correct responses.

3.3.6 Data analysis.

Between group demographic comparisons were conducted using paired samples t-tests. Subjective ratings for balance confidence and fall anxiety were collapsed across instructional sets and compared across the LO and HI height using a non-parametric Freidman test. Galvanic skin conductance values were normalized to the baseline seated condition and logarithmic transformed to reduce the effect of skewness and kurtosis. The transformed GSC values were compared across height, instructional set, and age using a 3-factor [(Height (LO/HI) x Instruction (NP/PP/CP) x Age (YA/OA)] Repeated Measures Analysis of Variance (RM ANOVA). Separate 3-factor [(Height (LO/HI) x Instruction (NP/PP/CP) x Age (YA/OA)] RM ANOVA were used to determine the effect of platform height, instructional set, and age on postural control and cognitive performance. A 2-factor [Height (LO/HI) x Age (YA/OA)] RM ANOVA was used to determine the statistical relevance of the m-AAI values. Paired or independent t-tests were used to make between and within group comparisons when statistical significance for the RM ANOVA was achieved. Statistical significance was set at 0.05.

3.4 *Results*

3.4.1 Participant data.

Demographic data for YA and OA is summarized in Table 3.1. Scores for MMSE and ABC were not collected for younger adults as these questionnaires are specific to older populations. Paired samples t-test revealed no significant difference for the ratio of males and females ($p > 0.05$).

Table 3.1 *Demographic data for younger and older adult participants included in data analysis.*

	Younger Adults (n=15)	Older Adults (n=16)
Age	22.5 (2.4)	68.7 (4.7)
Gender	8 males / 7 females	6 males / 10 females
Height*	175.1 (9.6)	163.1 (6.4)
Weight	74.4 (14.9)	72.7 (12.6)
MMSE	NA	29.0 (1.0)
ABC	NA	94.1 (5.5)

* $p < 0.001$

3.4.2 Physiological and psychological measures. Due to instrumentation complications GSC data from 20 of a possible 31 subjects (12/15 YA and 8/16 OA) were used for analysis of physiological arousal. A main effect for height ($F(1, 18) = 20.50$, $p < 0.001$) revealed that physiological arousal was greater in the HI compared to the LO condition. Comparison of normalized values indicated that physiological arousal increased approximately 25% for YA and 65% for OA from the LO to HI conditions (Figure 3.3). A significant effect for surface height manipulation was also revealed for measures of balance confidence and fall anxiety. Results from a non-parametric Freidman test indicated that ratings for fall anxiety increased by approximately 10% and balance confidence ratings decreased approximately 6% with increased platform height. No significant interactions or group differences were established for fall anxiety ($p > 0.05$) or balance confidence ($p > 0.05$).

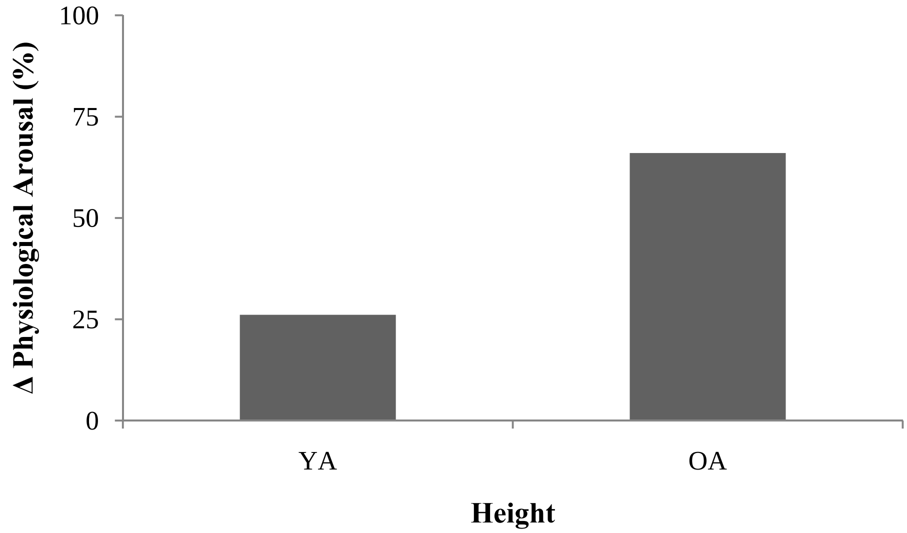

Figure 3.3 The percentage increase of physiological arousal from the LO to HI threat among younger and older adults.

3.4.3 Cognitive task performance. A main effect for Instruction ($F(2, 58) = 149.66$, $p = 0.05$) and an Instruction x Age interaction ($F(2, 58) = 233.29$, $p = 0.013$) were revealed for response accuracy. Follow-up comparisons indicated that response accuracy was significantly lower for NP instructions compared to PP instructions ($p = 0.014$) and CP instructions ($p = 0.009$) among OA. No significant differences for response accuracy were found between instructional sets.

Reaction time scores were significantly slower for OA across all instructional sets ($F(1, 29) = 43.5$, $p < 0.001$). A main effect for Instruction ($F(2, 58) = 4.11$, $p = 0.032$) revealed that reaction time was longer for NP compared to CP instruction ($p = 0.028$), however no difference was established between PP and CP or PP and NP ($p > 0.05$) . An Instruction x Age interaction ($F(2, 58) = 4.53$, $p = 0.023$) indicated that reaction time was longer for NP instruction compared to PP instruction ($p = 0.001$) among OA (Figure 3.4a and b), however no difference between NP and CP or PP and CP was established. On the contrary, follow-up comparisons indicated that YA had faster reaction times for CP compared to PP instructional sets ($p = 0.008$), however no difference between CP and NP instruction or PP and NP instruction was revealed. The manipulation of surface height did not influence reaction time for either group ($p = 0.87$).

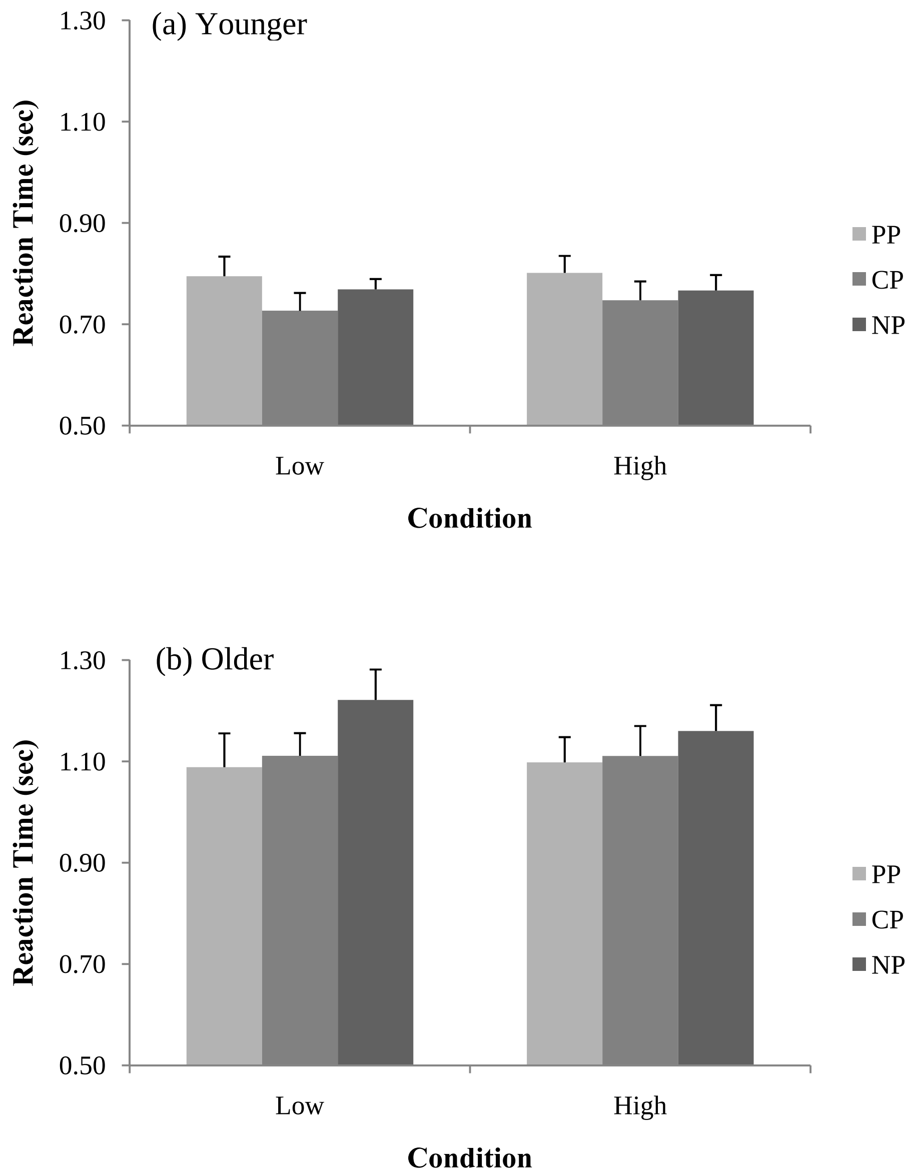

Figure 3.4 The effect of anxiety and instructional prioritization on verbal reaction time among younger adults (a) and older adults (b).

3.4.4 Postural control. There was a significant reduction of ESA in the HI versus LO condition ($F(1, 29) = 4.81$, $p = 0.036$). In addition, a main effect for Instruction ($F(2, 58) = 6.68$, $p = 0.002$) revealed that ESA was larger for CP compared to NP ($p = 0.015$) and PP ($p = 0.005$) instructional sets (Figure 3.5a and b). No age difference for posture was revealed ($p = 0.88$). Despite the absence of an age main effect, a Height x Instruction x Age interaction indicated that the effect of Height on instructional set differed between YA and OA ($F(2, 58) = 4.96$, $p = 0.01$). Follow-up comparisons of this 3-way interaction indicated that regardless of Height, YA had a larger ESA for the CP instruction compared to PP ($p = 0.006$) however no difference was established between NP and CP or PP. Conversely, a Height x Instruction interaction was established among the OA, characterized by a significantly larger ESA during CP instruction in the LO condition compared to the HI condition ($p = 0.006$).

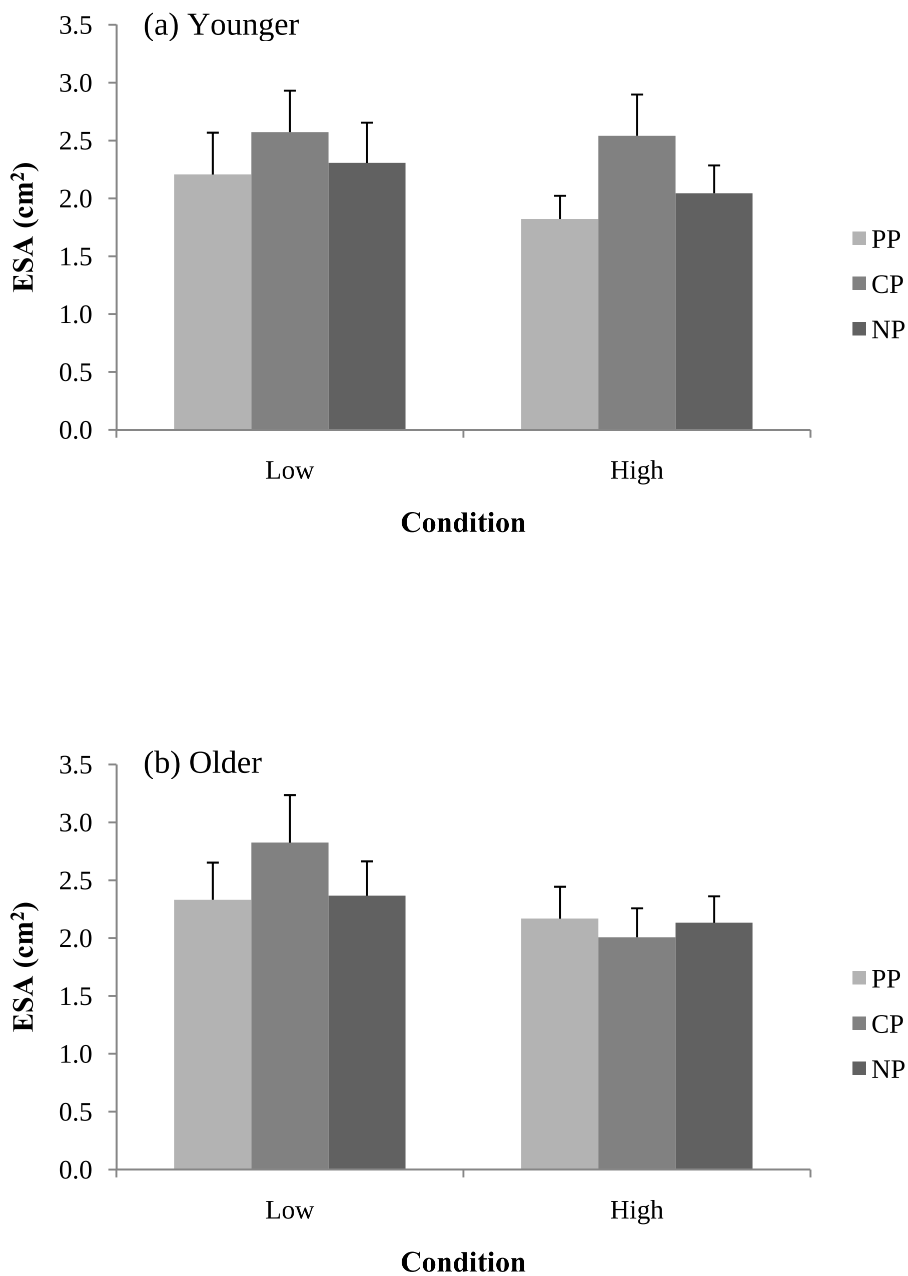

Figure 3.5 The effect of height and instructional prioritization on postural control among younger adults (a) and older adults (b)

3.4.5 Flexible resource allocation.

3.4.5a Cognitive task. A main effect of Age ($F(1, 29) = 7.72$, $p = 0.009$) confirmed that mAAI differed between age groups. This difference was characterized by a positive mAAI score for YA and a negative score for OA (Figure 3.6a). However, platform surface height did not differentially affect the cognitive task mAAI scores between YA and OA ($p = 0.72$).

3.4.5b Postural task. A main effect for Age indicated that scores on the mAAI for posture differed between YA and OA as evidenced by a larger positive mAAI value for YA compared to OA ($F(1, 29) = 4.47$, $p = 0.043$). Scores for the postural control mAAI revealed an Age x Height Interaction ($F(1, 29) = 4.03$, $p = 0.054$) characterized by positive mAAI scores for both age groups in the LO condition, however in the HI condition YA demonstrated a positive score whereas OA displayed a negative score (Figure 3.6b).

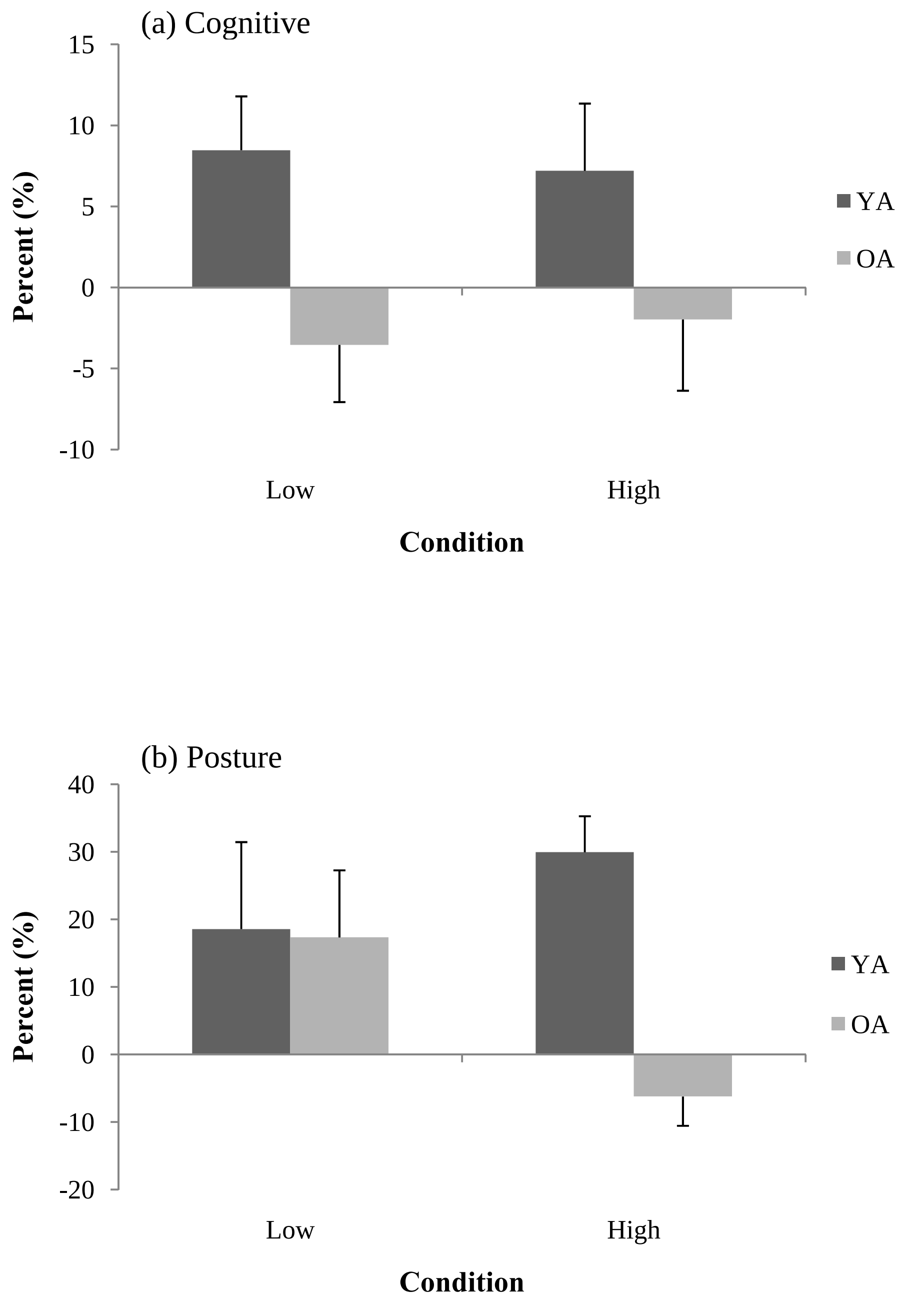

Figure 3.6 Modified Attentional Allocation Index scores for younger and older adult verbal reaction time (a) and postural control (b)

3.5 *Discussion*

The purpose of this study was to determine the influence of postural anxiety on flexible allocation of attention among YA and OA. To impose postural anxiety, I used the postural threat paradigm. In accordance with previous work in this area, physiological and psychological indices confirmed that elevation of the support surface increased physiological arousal (Adkin, et al., 2002; Brown & Frank, 1997; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001) while reducing balance confidence and increasing fall anxiety (Adkin, et al., 2002; Davis, et al., 2009; Huffman, et al., 2009). Consistent with previous studies (Adkin, et al., 2002; Brown & Frank, 1997; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001; Davis, et al., 2009; Huffman, et al., 2009) I have interpreted these findings to indicate that participants experienced increased anxiety about falling in the elevated testing condition compared to the ground level testing condition. The indices of cognitive and postural performance were also in agreement with documented findings regarding the effect of postural anxiety on cognitive and motor contributions to postural control (Adkin, et al., 2000; Brown & Frank, 1997; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001; Davis, et al., 2009), and I have interpreted this result as further substantiation that increased support surface height increased postural anxiety. The primary finding from my study was that the ability to flexibly allocate attention was compromised among OA in circumstances of increased anxiety. Based on previous studies confirming that postural anxiety influences the allocation of attention to prioritize postural control, it seems that compromised FRA is a subsequent consequence of the strengthened 'posture priority' attentional strategy that accompanies situations of heightened postural anxiety.

3.5.2 Effect of explicit prioritization on posture and cognitive task performance. Younger adults altered postural and cognitive performance according to instructional set as evidenced by a reduction of postural sway during PP instruction and improved cognitive task performance during CP instruction in both threat conditions. These findings support previous research and substantiate the ability of YA to flexibly allocate attention (Siu, et al., 2008; Siu & Woollacott, 2007; Yogev-Seligmann, et al., 2009). This conclusion is also supported by the composite score of FRA as indicated by the positive mAAI scores for posture and cognitive performance in both threat conditions. This finding supports and extends previous research indicating that YA can flexibly allocate attention between a cognitive and postural task (Siu, et al., 2008; Siu & Woollacott, 2007). As demonstrated by Siu et al. (2008), YA reduced gait velocity during obstacle crossing and improved cognitive task performance when instructed to prioritize walking and cognitive task performance respectively (Siu, et al., 2008). The interesting finding was that indices of cognitive and postural performance complied with the instructional priorities among YA when postural anxiety was heightened. From this finding it seems that anxiety does not disrupt FRA among YA. It is possible however, that the postural manipulation did not sufficiently increase postural anxiety as evidenced by the larger increased in physiological arousal among OA compared to YA. Nevertheless, YA did indeed exhibit increased physiological arousal as demonstrated from the GSC data and reported reduced balance confidence and increased fall anxiety in the HI threat condition. Alternatively, it is possible that YA had superior attentional resources that were not influenced by postural anxiety.

In contrast to my finding for YA, results indicated that FRA among OA was affected by postural anxiety. This interpretation is based on the absence of change in postural or cognitive performance according to instructional set in the HI threat condition. Specifically, postural sway was significantly greater during CP instruction in the LO threat compared to the HI threat condition. It seems that postural anxiety strengthened the attentional bias to posture resulting in a prioritization of postural stability. This possibility is supported by increased postural stability in the HI compared to LO threat conditions and further substantiates previous research demonstrating an age difference in the ability to flexibly allocate attention (Siu, et al., 2008). Moreover, these results extend previous findings indicating that increased anxiety about falling differentially affects YA and OA (Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002). It is also possible that in the absence of postural anxiety, OA attempted to allocate attention to the cognitive task at the expense of postural performance. Alternatively, during circumstances of postural anxiety, OA sacrificed cognitive task performance to preserve postural control. These results are in line with the 'posture first' strategy and support those of Doumas et al. (2008) who demonstrated that OA reduced postural performance and improved cognitive performance when posture was not challenged (Doumas, et al., 2008). Alternatively, when a challenge to posture was introduced OA improved postural stability while reducing cognitive task performance (Doumas, et al., 2008). Results in the current study from the mAAI scores for cognitive performance indicated a significant age difference suggesting that the degree of FRA was greater among YA. Conversely, for the postural mAAI, both age groups demonstrated positive values in the LO threat condition, however FRA in the HI condition diminished among OA but remained for YA. This result further substantiates my findings indicating that FRA is compromised in contexts of increased postural anxiety.

Comparison of postural and cognitive task performance during the NP instructional set to performance during CP and PP instructional sets provided some interesting insight regarding the natural context for attentional allocation. As evidenced by no change in cognitive task performance when comparing PP and CP to NP instructional set, it seems that YA do not prioritize task performance to the postural or cognitive task in the absence of instructional sets. Conversely, postural and cognitive performance did not differ between NP and PP instructional sets among OA in either height condition. These findings provide an extension to those of Siu and colleagues and infer that YA have sufficient attentional resources to successfully perform a postural and cognitive task in the absence of instructional sets. Conversely, it seems that OA prioritize postural control regardless of postural anxiety when not provided with instructional sets. This result substantiates previous research indicating a natural bias for the control of posture (Bloem, et al., 2006; Bloem, et al., 2001; Brauer, et al., 2001; Brown, Sleik, et al., 2002; Li, et al., 2001; Muller, et al., 2007; Rapp, et al., 2006; Shumway-Cook, Woollacott, et al., 1997; Yogev-Seligmann, et al., 2008).

3.6 *Conclusion*

Results from this study indicated that FRA was compromised among OA in circumstances of increased postural anxiety, yet YA maintained this capacity regardless of postural anxiety. This finding presents the possibility of situation-dependent limitations for adopting FRA as a strategy for managing dual task challenges among OA. Therefore, compromised FRA among aging populations may reduce the ability to identify and avoid potential hazards and subsequently increase fall prevalence. Findings from this study may be beneficial for clinicians and researchers alike when prescribing or designing dual task training protocols. For example, dual task training protocols focused on training aspects of executive function, such as FRA, could be used among elderly populations who fear falling. In conclusion, future research should be directed to understanding FRA among fall fearful OA.

Chapter 4: Experiment 2 – The Influence of Concurrent Postural Challenge and Postural Anxiety on Flexible Resource Allocation among Younger Adults

4.1 Abstract

Flexible Resource Allocation, in which attention is alternated between concurrent tasks, has been identified as one strategy to manage multitask scenarios. In my previous experiment I demonstrated compromised FRA among OA during circumstances of heightened postural anxiety. This effect was not observed among YA. One possible avenue of study from this observation was whether the capacity for FRA during heightened postural anxiety could be sustained when posture was challenged. To explore this possibility, I varied support surface stability using a fixed and sway referenced surface in conditions known to heighten postural anxiety. Participants performed a cognitive task concurrent to these postural manipulations according to three task priority instructional sets. Elliptical sway area (ESA) and verbal reaction time (VRT) were acquired from ground reaction forces and verbal responses. Results indicated that YA altered VRT according to instructional set without compromising posture. This finding suggests that despite postural challenge during heightened postural anxiety, YA maintain the capacity to automatically prioritize posture while performing a secondary task.

4.2 Introduction

The control of posture and gait requires attention and executive resources similar to those involved in cognitive processes (Badgaiyan, 2000; Kerr, et al., 1985; Sheridan & Hausdorff, 2007). Therefore, simultaneous performance of a postural and cognitive task, as is often required in activities of daily living, demands that attentional resources be dually provided to both tasks. As stated by the the Limited Capacity Theory (Kahneman, 1973), if the attentional requirements of a multitask scenario exceed the available attentional resources, decrement will occur for one or both tasks. The attentional strategies that are considered to be used for managing multitask scenarios include the division of attention and set-switching of attention. Divided attention involves parsing of attentional resources between tasks while set-switching involves the dynamic interchange of attentional resources between tasks. Task prioritization is an aspect of the divided attention strategy characterized by an unequal distribution of attentional resources between tasks. Conversely, FRA is characteristic of set-switching where attentional resources are 'flexibly' allocated between multiple tasks.

The prioritization of postural control, known as the 'posture first' strategy is recognized as a natural and unconscious bias to postural control (Bloem, et al., 2006; Bloem, et al., 2001; Brauer, et al., 2001; Brown, Sleik, et al., 2002; Li, et al., 2001; Muller, et al., 2007; Rapp, et al., 2006; Shumway-Cook, Woollacott, et al., 1997; Yogev-Seligmann, et al., 2008) that reflects various factors relating to participant traits, the characteristics of the postural task, and the instructions directing task priority (Shumway-Cook, Woollacott, et al., 1997). Although postural prioritization is evident in normal circumstances, it is increasingly prevalent when postural challenge (Doumas, et al., 2008) or postural anxiety (Brown, Sleik, et al., 2002) is imposed. In support of this phenomenon, research has demonstrated that OA require greater attentional resources for the control of posture than YA (Lajoie, et al., 1996; Marsh & Geel, 2000; Woollacott & Shumway-Cook, 2002). While this 'posture first' strategy may optimize postural performance, it may also compromise the availability of attentional resources, such as those needed for the identification of potential hazards to postural stability. One potential benefit of FRA that may supersede the benefits of parsed attention is that attentional resources can be dually provided with minimal task decrement. This possibility is supported by recent research demonstrating that YA and OA were able to successfully perform a walking task simultaneously with a cognitive task by flexibly allocating attention when provided with task priority instructional sets (Siu, et al., 2008). The capacity for FRA however, was compromised among balance impaired OA (Siu, et al., 2008; Siu, et al., 2009) suggesting that reduced ability for FRA may be contributing factor for fall risk among OA.

The current state of research in our laboratory focuses on understanding the attentional contributions to postural control. Aligned with this research focus, the first experiment in my thesis demonstrated that postural anxiety compromised the capacity for FRA among OA but not among YA. From this finding one possibility that can be explored is whether the capacity for FRA in states of postural anxiety among YA can be sustained when postural control is challenged beyond that of static stance. To address this possibility and to probe the extent of FRA among YA, I varied the testing protocol from the first experiment by imposing a challenge to posture during circumstances of heightened postural anxiety. Therefore, the purpose of this study was to investigate the effect of concurrent postural anxiety and postural challenge on the ability to flexibly allocate attention. To the best of my knowledge, previous research has yet to investigate the influence of simultaneous postural challenge and postural anxiety on FRA. Understanding this phenomenon may further our knowledge regarding the limitations of FRA. To answer this research question I manipulated postural anxiety in accordance with the postural threat paradigm by increasing platform surface height and I imposed a challenge to posture by perturbing the support surface. Based on previous research (Siu, et al., 2008; Siu & Woollacott, 2007), I hypothesized that YA would flexibly allocate attention in all conditions of postural threat and postural anxiety however, the combination of postural challenge and postural anxiety would result in compromised FRA.

4.3 Methods

4.3.1 Participants. Twelve younger adults (YA; age, 20.5 ± 0.53 years) were recruited from the University of Lethbridge to participate in this study. All participants were free of self-reported orthopaedic pathology that may have adversely affected their ability to comply with the experimental procedures. Ethical approval was provided by the Human Research Ethics Committee of the University of Lethbridge prior to subject recruitment. Voluntary written informed consent was provided by all participants preceding any experimental procedure.

4.3.2 Protocol. Participants performed a postural and cognitive task simultaneously in four conditions of postural threat and according to three instructional sets directing task priority. Participants stood on the force platform (AMTI®, Watertown, MA, USA) located within the NeuroCom Clinical Research System® (Neurocom, Clackamas, OR, USA) and were instructed to stand quietly with arms positioned at their side while performing all trials. Challenge to postural control was imposed by varying the stability of the support surface upon which the participants stood. Specifically, a fixed support surface (FIX) in which the surface was stable and a sway referenced support surface (SR) in which the support surface moved in direct accordance to participant movement were used. Postural anxiety was manipulated using the surface height model (Brown & Frank, 1997) with two vertical platform heights set at 0.6 meters above ground level (Low Threat; LO) and 1.4 meters above ground level (High Threat; HI). By combining the postural challenge and postural anxiety conditions, four postural conditions were used: LO_FIX, LO_SR, HI_FIX, HI_SR. Specific details on the postural manipulations are provided in section 4.3.3. The Color Word Stroop (Stroop) task (Ben-David & Schneider, 2009) was the cognitive task selected for this study. The Stroop task required participants to provide an accurate and time-dependent response to a probe word. Specific details of the task are provided in section 4.3.4. A partial Latin square design was used to balance presentation order between participants (Table 4.1). The cognitive and postural task were performed simultaneously in each testing condition according to three instructional sets directing task priority as follows:

No priority (NP) – No instruction provided.

Posture priority (PP) – Focus your attention on your posture so that you stand as still as possible while still completing the cognitive task.

Cognitive priority (CP) – Focus your attention on the cognitive task so that you respond as quickly and accurately while still maintaining your balance.

The purpose of the NP instruction trials was to provide an indication of natural self-directed priority. Therefore, participants performed the posture and cognitive task in each postural condition according to the NP instruction prior to the CP and PP instruction trials to avoid any bias during the NP instruction. One 60 second trial was performed in each postural condition according to each instructional set for a total of 12 experimental trials.

Table 4.1 *Presentation order for postural conditions*

Presentation Number	Presentation Order
1	LO_FIX, LO_SR, HI_FIX, HI_SR
2	LO_SR, LO_FIX, HI_SR, HI_FIX
3	HI_FIX, HI_SR, LO_FIX, LO_SR
4	HI_SR, HI_FIX, LO_SR, LO_FIX

Participants were equipped with a whole body harness secured to a support beam mounted on the ceiling and were spotted by a research assistant at all times. Participants were familiarized to the cognitive task while seated. Once confident with the Stroop task, a seated assessment was obtained to provide an index for baseline cognitive task performance. A baseline assessment of physiological arousal was also acquired while seated and standing at ground level. Subsequent to baseline data collection, participants were positioned on the NeuroCom force platform and performed the cognitive task in each testing condition for all instructional sets. Upon completion of each trial, subjective ratings of fall anxiety, balance confidence and perceived stability were collected using a Likert scale. Specifically, participants were asked to rate their anxiety about falling during the preceding test on a scale of 0% (not anxious at all) to 100% (extremely anxious). Balance confidence was assessed by asking participants to rate their confidence in their ability to maintain their balance during the preceding test on a scale of 0% (no confident at all) to 100% (completely confident). Participants were then asked to rate their perceived stability during the preceding test on a scale of 0% (completely unstable) to 100% (completely stable).

In addition to these psychological indices of fall anxiety, a modified version of the Movement Specific Reinvestment Scale (MSRS), comprised of the Movement Self-Consciousness (MSC) subscale and the Conscious Motor Processing (CMP) subscale, was used to assess state-related movement reinvestment (Huffman, et al., 2009). For example, question three of the CMP subscale required participants to rate their response on a 6 point likert scale (1 = strongly disagree to 6 = strongly agree) to the statement, "I was always trying to think about my movements when I carried them out standing at this height”. The questions for the MSC subscale were structured in a similar way. For instances, question two of the MSC required participants to rate their “concern about their style of moving when standing at this height” using the same 6 point likert scale as the CMP subscale.

4.3.3. Postural task. The NeuroCom Clinical Research System® was used to manipulate postural challenge by sway referencing the support surface. Support surface sway referencing involves the rotation of the force platform about a central axis that occurs in proportion to center of pressure displacement in the anterior-posterior direction. The sway referenced support surface challenges postural control by compromising the accuracy of somatosensory feedback. Previous research protocols have used a gain of one (Shumway-Cook & Woollacott, 2000) where platform rotation occurs in direct proportion to the magnitude of center of pressure displacement. Posture can be challenged further by altering the gain of sway reference. A gain greater than one, as employed in previous research (Clark & Riley, 2007; Doumas, et al., 2008), increases the responsiveness of the support surface resulting in faster and larger amplitude platform displacements occurring in the same direction of participant sway. Alternatively, employing a negative gain results in similar support surface responsiveness with respect to the selected gain however, platform displacement occurs in the opposite direction that the participant is moving. For the purpose of this study I selected a gain of negative two in which support surface responsiveness is twice that when using a gain of one resulting in faster and greater platform rotations in the opposing direction that the participant is swaying. A negative gain of two was selected to ensure sufficient postural challenge.

This selection was based on pilot testing exploring various sway reference gains and the superior postural tolerance demonstrated among YA.

4.3.4 Cognitive task. The Stroop task (Figure 4.1) was viewed on a computer monitor (19 inch) positioned at eye level approximately 80 cm away. The task began with the presentation of a fixation point located in the center of a white background. The fixation point was presented for two seconds, after which, one of the following four probe words appeared for two seconds: “RED”, “BLUE”, “GREEN”, or “YELLOW”. The probe word was printed in a font color corresponding to one of the remaining three colors, thereby making all color-word pairings incongruent. Participants were instructed to respond to the probe word by reciting the font color of the probe word rather than reciting the probe word itself. The combination of fixation point and probe word presentation repeated 15 times throughout the duration of the trial.

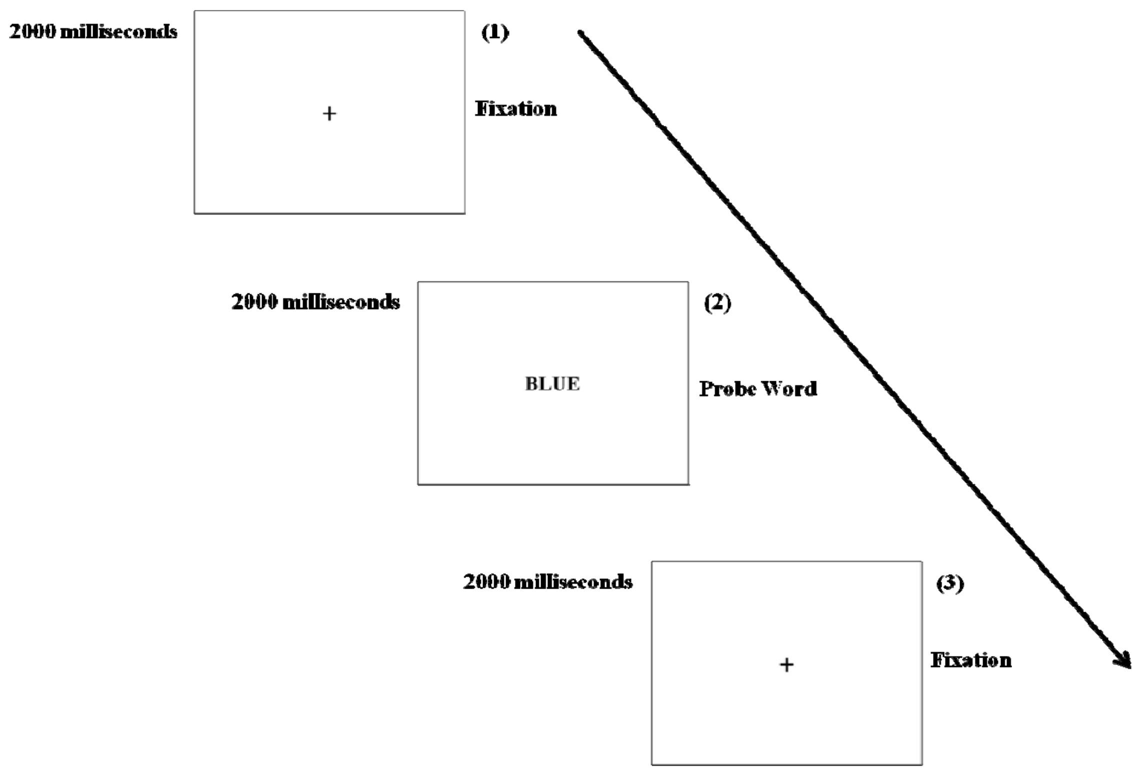

Figure 4.1 The Stroop task began with the presentation of a fixation point for 2000 milliseconds. Subsequently, a probe word was display for 2000 milliseconds. In the current example, the probe word 'BLUE' was printed in the color green, therefore the correct response would be 'green'. Following the presentation of the probe word a fixation point was displayed once again and the previously described sequences repeated.

4.3.5 Instrumentation and data processing. The NeuroCom Clinical Research System®, equipped with dual locked mechanical force plates and a three sided visual surround capable of rotation in the sagittal plane about a central axis was used to manipulate and measure postural control. The visual surround was removed and the base was firmly positioned on the hydraulic lift (1.2 × 1.8m; Pentalift, Guelph, ON) used to manipulate surface height. Ground reaction forces and moments of force in the three orthogonal axes were filtered using a fourth order dual pass Butterworth filter with a cut-off frequency of 5 Hz. Filtered ground reaction and moment forces were processed using custom written algorithms (MATLAB) to determine center of pressure location in the anterior posterior and medial lateral directions. Posture data were sampled at a frequency of 100 Hz. The Stroop Task (Ben-David & Schneider, 2009) was created using graphical interface experimental design software (E-Prime 2.0). The Stroop task program emitted two auditory signals used to identify (1) trial initiation and (2) the onset of a probe word (Figure 4.2). Verbal responses for the Color-Word Stroop task were acquired using a head-mounted microphone and an auditory recording device (iPod®). Galvanic skin conductance was collected using two silver/silver chloride electrodes connected to a BioDerm Skin Conductance Level Meter (UFI, Morro Bay, CA). The electrodes were fastened to the intermediate phalanges of the third and fourth digits for the duration of the testing. Data points from the initial 10 seconds of GSC collection were used to infer the physiological response in each trial. The auditory signals, verbal responses and GSC signals were sampled at a frequency of 600 Hz using an analog to digital interface (Vicon Motus 9.0 software, Englewood, CO, USA). Verbal reaction time and values for GSC were calculated from raw unfiltered data points using custom written algorithms (MATLAB).

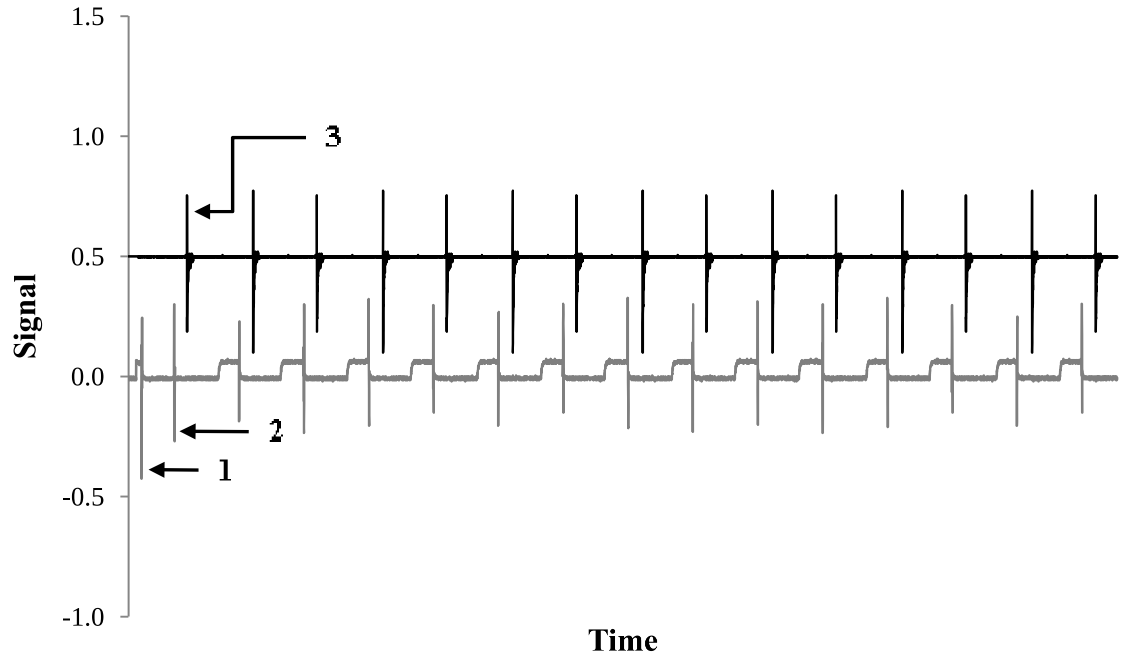

Figure 4.2 An auditory signal (1) was emitted by the E-Prime program to indicate trial initiation. Following trial commencement, a separate auditory signal (2) corresponding to the onset of a probe word was emitted. The microphone signal is overlayed above the E-Prime signal that illustrates verbal responses (3) with respect to the onset of a probe word.

4.3.6 Measures of interest. Elliptical Sway Area (ESA) and Verbal Reaction Time (VRT) were selected as the indices used to summarize postural and cognitive performance in this study. Elliptical sway area was calculated using a 95% confidence interval in which the ellipse encompasses 95% of the COP trajectory. The ESA calculations were based on the principal components analysis method in which the eigenvalues of the covariance matrix between the anterior-posterior and medial-lateral COP trajectories were used to determine the ellipse. The time interval between probe word onset and the verbal response was used to calculate VRT. These indices of postural control and cognitive performance were input into the Modified Attentional Allocation Index (m-AAI) to quantify FRA. The m-AAI was modified from the original algorithm (Siu & Woollacott, 2007) in such a way that positive values would represent FRA relative to natural self-selected task prioritization. Verbal response accuracy was determined by comparing the recorded color responses to the correct documented responses.

4.3.7 Data analysis. Galvanic skin conductance values were collapsed across all instructional sets and compared for the effects of height and surface condition on physiological arousal using a 2-factor [Height (LO/HI) x Surface (FIX/SR)] Repeated-Measures Analysis of Variance (RM ANOVA). A 2-factor [Height (LO/HI) x Surface (FIX/SR)] RM ANOVA was performed to determine the influence of height and surface condition on subjective ratings for balance confidence, fall anxiety and perceived stability. Verbal reaction time, response accuracy, and MSRS data were analyzed separately using a 3-factor [Height (LO/HI) x Surface (FIX/SR) x Instruction (NP/PP/CP)] RM ANOVA to determine the effect of height, surface and instructional set.

Similarly, posture data were analyzed using a 3-factor [Height (LO/HI) x Surface (FIX/SR) x Instruction (NP/PP/CP)] RM ANOVA to establish the influence of height, surface, and instructional set on ESA. A 2-factor [Height (LO/HI) x Surface (FIX/SR)] RM ANOVA was used to determine the effect of height and surface condition on FRA. Paired samples t-tests with Bonferroni correction were used to make between and within group comparisons when significance for the RM ANOVA was achieved. Statistical significance was set at 0.05.

4.4 *Results*

4.4.1 Participants. Twelve subjects enrolled and participated in this study. Participant demographics are summarized in Table 4.2.

Table 4.2 *Subject demographics. The mean and standard deviation for age, height and weight.*

	Participants (7 females)
Age	20.5 (0.53)
Height (cm)	170.2 (2.69)
Weight (kg)	70.9 (3.45)

4.4.2 Physiological and psychological response. A main effect of Height revealed that physiological arousal was greater in the HI compared to the LO condition ($F(1,11) = 5.47$, $p = 0.039$). Specifically, physiological arousal was approximately 5% greater in the HI condition compared to the LO condition (Figure 4.3). No effect of Surface condition on physiological arousal or a Surface x Height Interaction was established ($p > 0.05$).

Examination of subjective ratings for balance confidence, fall anxiety, and perceived stability revealed that balance confidence was significantly reduced during postural challenge ($F(1,11) = 54.55$, $p < 0.001$). Similarly, perceived stability was reduced when a challenge to posture was imposed ($F(1,11) = 43.87$, $p < 0.001$). Despite the influence of postural challenge on balance confidence and perceived stability, no significant increase in fall anxiety was reported ($p > 0.05$). No additional main effects or interaction effects were established ($p > 0.05$).

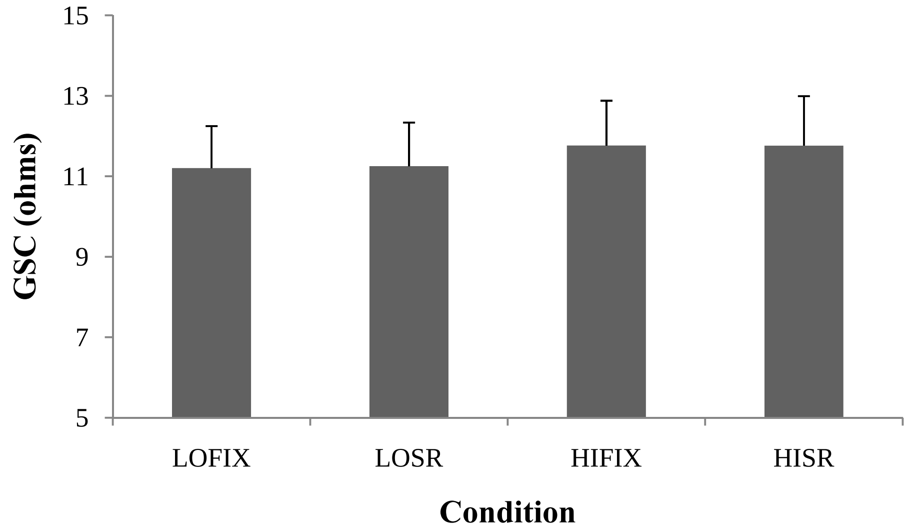

Figure 4.3 Postural arousal during the initial ten seconds of each postural condition.

Results from the MSRS subscales indicated that Instructional set significantly influenced conscious motor processing ($F(2,22) = 16.02$, $p < 0.001$) and movement self-consciousness ($F(2,22) = 4.26$, $p = 0.029$). Follow up comparisons indicated that conscious motor processing was greater during PP instructions compared to NP ($p = 0.001$) and CP ($p = 0.002$) instructions (Figure 4.4a). Moreover, follow up comparisons for the MSC revealed that movement self-consciousness was greater during NP compared to CP ($p = 0.010$) instructional sets (Figure 4.4b). An effect for Surface on CMP subscale revealed that conscious motor processing was greater when a challenge to posture was imposed ($F(2,22) = 10.01$, $p = 0.009$). No main effect of Surface was revealed for movement self-consciousness ($p > 0.05$). Despite this finding, the results revealed that Surface differentially influenced movement self-consciousness across Instructional sets ($F(2,22) = 3.78$, $p = 0.039$). Although, Surface condition affected movement self-consciousness, no influence of Height was revealed for movement self-consciousness or conscious motor processing ($p > 0.05$).

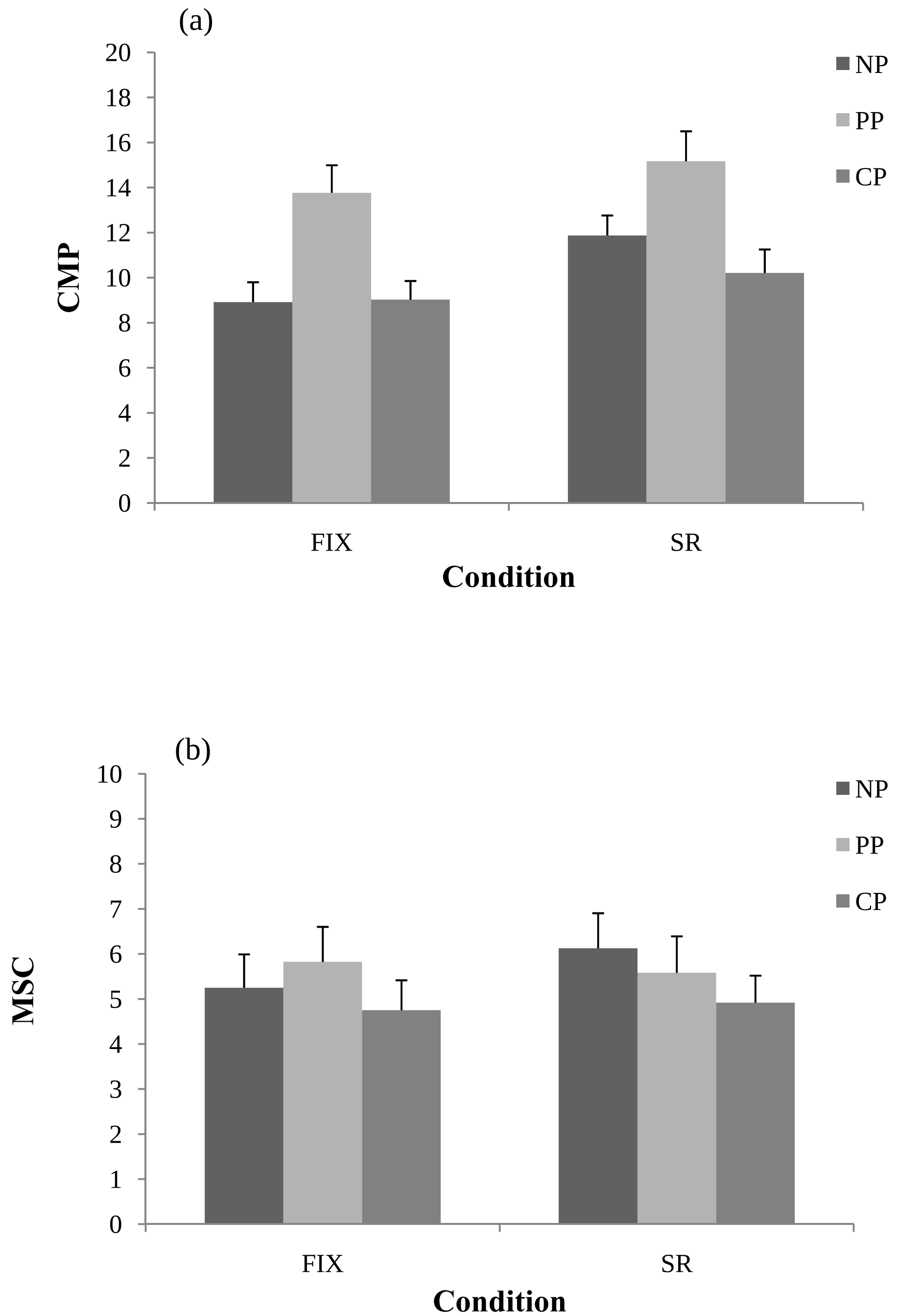

Figure 4.4 The influence of Instruction and Surface condition on (a) Conscious Motor Processing and (b) Movement Self-Consciousness.

4.4.3 Cognitive task performance. Performance accuracy for the Stroop task was not affected by Instructional set, Height, or Surface condition ($p > 0.05$). Accuracy rates did not fall below 98% despite manipulation of Height, Surface and Instructional set. Although response accuracy was not affected by the experimental manipulations, response time was affected by Instructional set ($F(2,22) = 6.90$, $p < 0.005$; Figure 4.5). Follow up comparisons revealed that VRT was longer during PP compared to CP instructions ($p = 0.008$). Moreover, a main effect for Surface ($F(2, 11) = 9.97$, $p = 0.009$) revealed that cognitive performance was reduced when a challenge to postural control was imposed. Despite the effect of postural challenge on cognitive task performance, no main effect or differential effect of Height was revealed ($p > 0.05$).

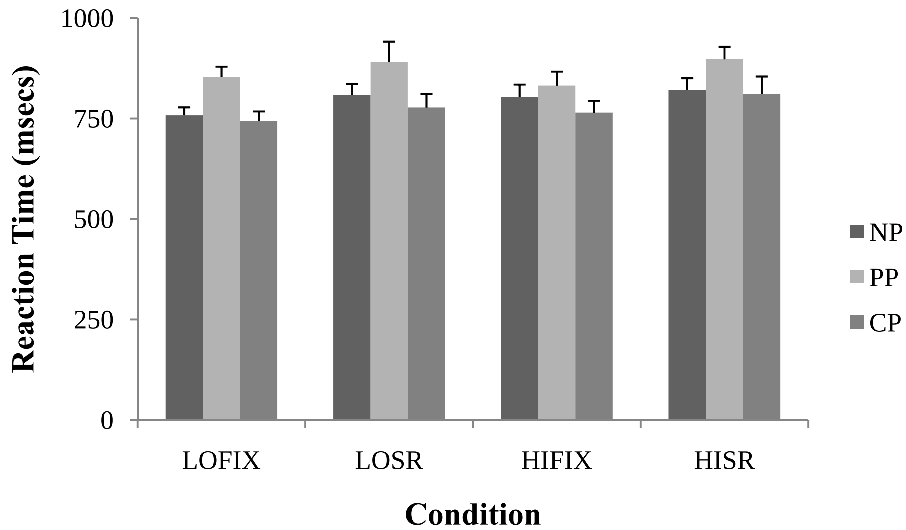

Figure 4.5 Cognitive task performance across three levels of Instruction in each postural condition.

4.4.4 Postural task performance. A main effect of Height ($F(1,11) = 5.12$, $p < 0.045$) revealed that ESA was significantly smaller in the HI threat compared to the LO threat condition (Figure 4.6). Postural sway was 10% greater in the LO compared to HI threat condition. Furthermore, postural sway was significantly greater when a challenge to postural control was imposed ($F(1,11) = 12.95$, $p = 0.004$). Specifically, during the SR condition, ESA increased to more than twice the ESA observed during the FIX condition. Although main effects for Height and Surface were established, no significant Height x Surface interaction was revealed ($p > 0.05$). An Instruction x Surface Interaction revealed ($F(2,22) = 4.26$, $p = 0.027$) that surface condition differentially affected postural performance across Instructional sets. Specifically, postural sway during NP instruction increased significantly from FIX to SR. No main effect for Instruction was revealed ($p < 0.05$)

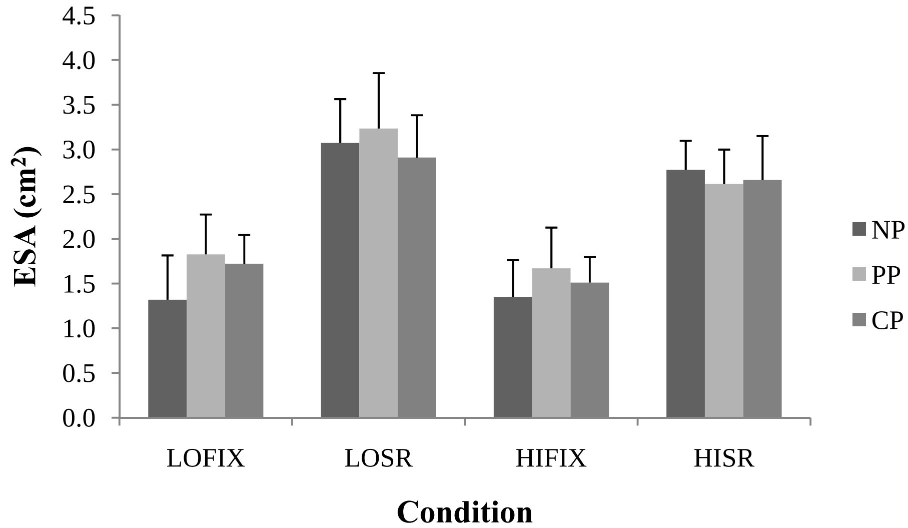

Figure 4.6 Postural sway according to instructional set in each postural condition.

4.4.5 Flexible resource allocation. Analysis of cognitive task m-AAI scores revealed no effect of Height ($p > 0.05$) or Surface ($p > 0.05$) condition on FRA (Figure 4.7). Cognitive task m-AAI scores were positive across all postural conditions indicating flexible allocation of attention to the prioritized task. Results from the postural task m-AAI were negative across all postural conditions indicating that attention was not flexibly allocated to the prioritized task (Figure 4.7). Despite this finding, no effect of Height ($p > 0.05$) or Surface ($p > 0.05$) condition was revealed.

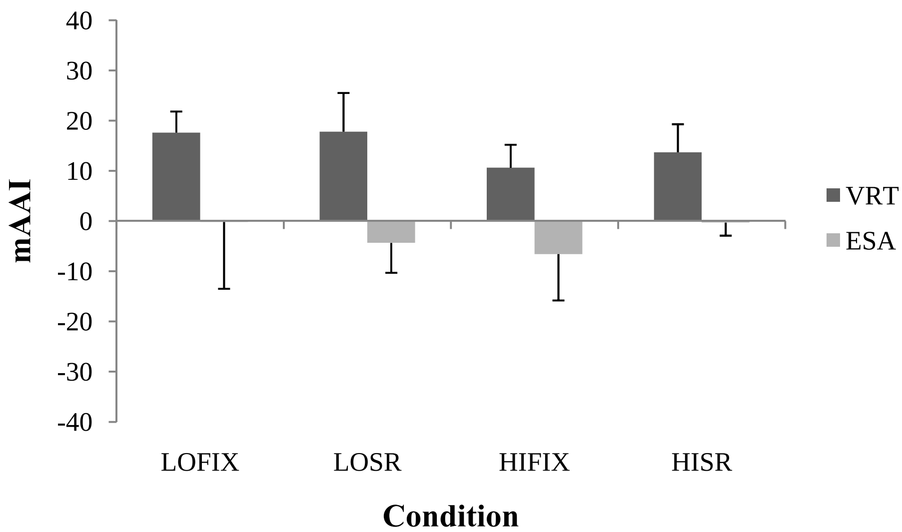

Figure 4.7 Modified Attentional Allocation Index scores for posture and cognitive task performance in each postural condition.

4.5 *Discussion*

The purpose of this study was to investigate the influence of simultaneous postural challenge and postural anxiety on the ability to flexibly allocate attention among YA. The challenge to postural control was imposed by sway referencing the support surface. Concurrent to the postural challenge, I manipulated postural anxiety in accordance with the surface height paradigm (Brown & Frank, 1997). As in previous research, physiological and psychological indices indicated heightened postural anxiety in the HI threat condition compared to the LO threat condition (Adkin, et al., 2002; Brown & Frank, 1997; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001). Subjective reports of balance confidence and perceived stability were also reduced during the SR compared to the FIX support surface. I interpreted these findings to indicate that participants experienced increased anxiety about falling in the HI condition and that the challenge imposed by the sway reference support surface altered perception and confidence regarding balance ability.

Indices of cognitive and postural performance paralleled those observed in previous research manipulating postural challenge (Doumas, et al., 2008; Redfern, et al., 2001; Shumway-Cook & Woollacott, 2000; Shumway-Cook, Woollacott, et al., 1997) and postural anxiety (Adkin, et al., 2000; Brown & Frank, 1997; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001; Davis, et al., 2009; Huffman, et al., 2009; Lamarche, et al., 2009). Specifically, postural stability was greater in the HI threat compared to the LO threat condition. Moreover, postural stability and cognitive performance diminished when a challenge to posture was imposed. I have interpreted this finding to further substantiate the influence of postural challenge and postural anxiety on the control of posture. Similar to the indices of physiological and psychological arousal however, there was no combined effect of postural challenge and postural anxiety. The main finding of this study was that a concurrent manipulation of postural anxiety and postural challenge did not influence FRA among YA. As justified in the subsequent sections, I have interpreted this finding to indicate strong capacity for FRA among YA that is not disrupted by postural anxiety and can be sustained despite postural challenge.

4.5.1 The influence of instructional set and postural manipulation on movement reinvestment. Explicit instructions directing task priority influenced the conscious control of movement as evidence by greater scores on the Conscious Motor Processing subscale during PP compared to NP and CP instructions. I have interpreted this finding to indicate that explicit instructions directing task priority to postural control resulted in a more conscious control of posture. This finding substantiates the use of instructional sets to manipulate task priority and supports the validity of the instructional set paradigm for the scenarios used in this study. As evidenced by higher ratings for conscious motor processing during the SR compared to FIX support surface, YA demonstrated greater conscious control of movement when presented with a postural challenge. This supports the findings of Huffman et al. (2009) who demonstrated that when postural anxiety was imposed using the surface height model, YA had greater conscious control of movement in the high threat compared to the low threat condition (Huffman, et al., 2009). I have interpreted my findings to further substantiate the use of the MSRS as an indicator of conscious control of movement during circumstances of postural challenge. An interesting finding that deserves further comment was that postural challenge differentially influenced concern about movement during the NP instructional set. From this finding it seemed that in the absence of priority instructions, participants were more aware of, and more concerned about, postural instability. Alternatively, heightened concern regarding postural stability may have also occurred due to the novelty of the moving platform. In this scenario however, I would expect a similar effect during NP for the CMP subscale. Curiously, I did not observe an effect of height on movement reinvestment. Although results for the current study indicated increased fall anxiety in the HI threat conditions, it is possible that platform height was not sufficient to induce increased movement reinvestment similar to that previously observed when using an extreme platform height of 3.2 meters (Huffman, et al., 2009).

4.5.2 The effect of prioritization on cognitive and postural task performance. As indicated by significantly longer VRT during PP compared to CP instructional sets, YA were able to alter cognitive task performance according to instructional set. This result supports my previous study findings and further substantiates the use of explicit instructions to direct attentional priority (Mitra & Fraizer, 2004; Siu, et al., 2008; Siu, et al., 2009; Siu & Woollacott, 2007; Yogev-Seligmann, et al., 2009). Performance of the postural task during the NP instruction was differentially affected by postural challenge, a finding that suggests the natural prioritization of posture is dependent upon postural challenge. The novel finding from this study however, was that YA alter cognitive performance according to instructional set without compromising postural control. Specifically, YA demonstrated no change in postural performance across instructional sets while improving cognitive performance during CP compared to

PP instruction. This finding is in agreement with that of Siu and Woollacott (2007) who demonstrated that YA altered cognitive task performance but not postural task performance according to instructional set (Siu & Woollacott, 2007). This finding from the work of Siu and Woollacott (2007) together with the findings from the current study, provide evidence to suggest that even when posture is challenged during heightened postural anxiety, YA maintain the capacity to automatically prioritize postural control while performing a secondary task. This interpretation was also supported by findings from the composite index of FRA indicating positive m-AAI scores for the cognitive task and slightly negative scores for the postural task across all testing conditions (Figure 4.7). The positive scores for the cognitive m-AAI indicated that YA allocated attention to the cognitive task during CP instructions but the negative scores for the postural m-AAI indicated that YA did not flexibly allocate attention to posture during PP instructions. This finding suggests that even when posture is challenged during circumstances of heightened postural anxiety, YA demonstrate the attentional capacity to automatically prioritize the control of posture while performing a secondary cognitive task.

4.6 *Conclusion*

Findings from the current study demonstrate that regardless of postural challenge and postural anxiety, YA maintain the capacity to flexibly allocate attention to a cognitive task without compromising performance of the postural task. This means that despite the presentation of postural challenge concurrently to heightened postural anxiety, YA have the capacity to automatically allocate sufficient attentional resources to maintain postural stability.

Chapter 5: General Discussion

The combination of falling and fear of falling constitutes a significant concern among the elderly. Falls are experienced by approximately one third of OA over the age of 65 (Rubenstein, 2006), approximately 50% of whom identify to a fear of falling (Zijlstra, et al., 2007). Falls are associated with various adverse health outcomes such as reduced quality of life and activities of daily living, depression and anxiety, social withdrawal, higher fall rates, and fear of falling (Legters, 2002; Tinetti & Williams, 1998). As substantiated by a dedicated line of research, the control of posture and gait require attention and executive function. When performing activities of daily living, posture and gait are often paired with additional task, thereby increasing the demand of attention and executive function. Various attentional strategies are available to manage such multitask scenarios, including FRA, in which attentional resources are alternately directed between tasks. Although FRA has been demonstrated as an effective management strategy for multitask scenarios, limited research has explored the influence of psychological factors such as anxiety, balance confidence and fear of falling on the capacity for FRA. As demonstrated by a substantiated line of research investigating the attentional contributions to postural control, it is possible that an underlying anxiety about falling, such as that experienced by fall fearful OA, may compromise the capacity for FRA. Therefore it is necessary to investigate the influence of fall anxiety on the strategies pertinent for the attentional contributions to postural control. This thesis contributes to and furthers the knowledge regarding the strategies used to direct attentional resources during circumstances of increased fall anxiety.

5.1 Heightened Postural Anxiety Influences the Flexible Resource Allocation Among Older Adults

The first experiment presented in this thesis investigated the effect of postural anxiety on the ability to flexibly allocate attention among YA and OA. My hypothesis for this experiment was that FRA would be compromised among OA in circumstances of postural anxiety. Specifically, I predicted that in the absence of postural anxiety, OA would alter cognitive and postural performance in accordance with instructional sets. Alternatively, when postural anxiety was present, the capacity for FRA would be compromised among OA. As a result, OA would adopt a posture first strategy characterized by improved postural stability and reduced cognitive task performance.

In accordance with previous research (Adkin, et al., 2002; Brown & Frank, 1997; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001; Davis, et al., 2009; Huffman, et al., 2009), postural anxiety influenced physiological and psychological indices of balance confidence and fall anxiety as well as the cognitive and motor contributions to postural control (Adkin, et al., 2000; Brown & Frank, 1997; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001; Davis, et al., 2009). The primary and most interesting finding of this study however, was that the capacity for FRA among OA was compromised during heightened postural anxiety.

As demonstrated by previous research, YA were able to alter cognitive and postural performance according to instructional set (Siu, et al., 2008; Yogev-Seligmann, et al., 2009). This result confirms and extends previous research indicating that the capacity for FRA remains among YA even during circumstances of heightened postural anxiety. In agreement with my hypothesis, the capacity for FRA among OA was compromised during circumstances of postural anxiety. Specifically, postural stability improved and cognitive task performance diminished when a challenge to posture was imposed. This finding is similar to those observed by Siu and colleagues (2009) demonstrating that the ability to flexibly allocate attention was compromised among balance impaired OA (Siu, et al., 2009). It seems that OA attempt to flexibly allocate attention in the absence of postural anxiety however, heightened postural anxiety seems to strengthen the bias of attention toward postural control, subsequently compromising the capacity for FRA.

Results from the NP instruction suggest that in the absence of instructional set, the attentional strategies differ between YA and OA. It seems that YA have sufficient attentional resources to automatically prioritize postural control when postural anxiety is heightened. Conversely, postural and cognitive performance during NP did not differ when compared to PP. This finding was interpreted to reflect a natural bias to postural control that confirms previous research demonstrating the adoption of a ‘posture first’ strategy among OA (Bloem, et al., 2006; Bloem, et al., 2001; Brauer, et al., 2001; Brown, Sleik, et al., 2002; Li, et al., 2001; Muller, et al., 2007; Rapp, et al., 2006; Shumway-Cook, Woollacott, et al., 1997; Yogev-Seligmann, et al., 2008).

5.2 The Influence of Concurrent Postural Challenge and Postural Anxiety on Flexible Resource Allocation Among Younger Adults

The purpose of the second experiment was to determine the influence of simultaneous postural challenge and postural anxiety on FRA among YA. In accordance with a substantiated line of research demonstrating the effect of postural challenge (Doumas, et al., 2008; Redfern, et al., 2001; Shumway-Cook & Woollacott, 2000;

Shumway-Cook, Woollacott, et al., 1997) and postural anxiety (Adkin, et al., 2008; Adkin, et al., 2000; Brown & Frank, 1997; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001; Davis, et al., 2009; Huffman, et al., 2009; Lamarche, et al., 2009), I hypothesized that combined postural challenge and postural anxiety would create a state of extreme postural anxiety that would compromise FRA among YA. Specifically, YA would alter cognitive and postural performance according to instructional set in the LO_FIX, LO_SR, and HI_FIX conditions while adopting a 'posture first' strategy in the HI_SR condition.

Physiological and psychological indices of postural anxiety indicated that the manipulation of platform surface height increased postural anxiety while postural challenge reduced balance confidence and perceived stability. Contrary to my hypothesis however, the addition of postural challenge during heightened postural anxiety did not create a state of extreme postural anxiety. Moreover, the motor and cognitive responses to postural challenge and heightened postural anxiety parallel previous research using the surface height paradigm (Adkin, et al., 2000; Brown & Frank, 1997; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002; Carpenter, et al., 1999; Carpenter, et al., 2001; Davis, et al., 2009; Huffman, et al., 2009; Lamarche, et al., 2009) and postural perturbations (Doumas, et al., 2008; Redfern, et al., 2001; Shumway-Cook & Woollacott, 2000; Shumway-Cook, Woollacott, et al., 1997) to manipulate the control of posture.

Findings from the Movement Specific Reinvestment Scale (Huffman, et al., 2009) revealed greater conscious control of movement during PP compared to CP and NP instructions as well as during the challenge to posture. These results were interpreted to indicate that YA altered attentional resources according to instructional set and that the challenge to posture increased to conscious control of posture. The primary result from the second study was that despite a challenge to posture during heightened postural anxiety, YA were able to alter cognitive performance according to instructional sets without compromising postural stability. Specifically, YA demonstrated faster VRT during CP compared to PP instruction and no change in ESA across instructional sets. These findings were congruent to, and provide an extension to those of Siu and Woollacott (2007) suggesting that even though posture was challenged concurrently to heightened postural anxiety, YA maintain the capacity to automatically allocate attention to the postural task while performing a secondary task (Siu & Woollacott, 2007). Therefore, it seems that a postural challenge during circumstances of heightened postural anxiety does not influence the automaticity of attentional allocation to the control of posture while performing a concurrent secondary task.

5.3 Integrated Discussion

The collective findings from the first and second study indicated that heightened postural anxiety compromises the capacity for FRA among OA while YA demonstrate the capacity to automatically prioritize posture, even when posture is challenged in circumstance of increased postural anxiety. The first experiment revealed that the capacity for FRA was compromised among OA during circumstances of heightened postural anxiety, yet YA remained able the flexibly allocate attention. It seemed that heightened postural anxiety did indeed strengthen the natural attentional bias towards postural control resulting in compromised FRA among OA. Curiously, heightened postural anxiety did not influence FRA among YA. Therefore, in the second study I varied the stability of the support surface to determine if the capacity for FRA could be sustained during heightened postural anxiety when posture was challenged beyond that of static stance. Findings within this study indicated that YA maintained the capability to alter cognitive performance according to instructional set without compromising postural stability.

One curious finding to emerge from the second study that contradicted the first study was the differing capacity for FRA among YA. One possible explanation to account for this occurrence was the differing cognitive tasks used in each study. The SMT used in experiment 1 had differing levels of difficulty that may have superseded the challenge presented by the Stroop task in the second experiment. It is possible that the greater attention required for the SMT may have resulted in greater postural sway during CP and subsequently provided more opportunity for improved postural stability during the PP trials. Nevertheless, it seems that YA retain the attentional capacity to alter cognitive task performance according to instructional set while allocating sufficient attention to the maintenance of postural stability.

The compromised capacity for FRA observed among OA during heightened postural anxiety is in agreement with Siu and colleagues (2009) indicating that the ability to flexibly allocate attention was impaired among balance impaired OA (Siu, et al., 2009). It seems that during circumstances of postural anxiety, the OA participants from this thesis demonstrated similar attentional strategies as balance impaired OA during dual task obstacle crossing. Moreover, the underlying tendency for a ‘posture first’ strategy is indeed strengthened among OA during states of heightened postural anxiety. Therefore, it seems that the strengthening of this psychological state by increasing platform surface height induced an attentional reorganization resulting in compromised FRA and the adoption of the ‘posture first’ strategy. This is in agreement with a documented line of research demonstrating the prevalence of the ‘posture first’ strategy among OA (Brauer, et al., 2001; Brown, Sleik, et al., 2002; Li, et al., 2001; Muller, et al., 2007; Rapp, et al., 2006; Shumway-Cook, Woollacott, et al., 1997; Yogev-Seligmann, et al., 2008). Although this strategy may optimize performance of the more important task, it may also compromise the ability to identify potential hazards to balance and subsequently increase fall risk.

Various attentional strategies are available to manage multitask scenarios, including FRA. In fact, previous research has indicated that the inability to flexibly allocate attention is a potential fall risk among OA (Lajoie, et al., 1993; Shumway-Cook & Woollacott, 2000; Shumway-Cook, Woollacott, et al., 1997), a claim that was further supported by Siu and colleagues (2009) who reveal that FRA was compromised among balance impaired OA (Siu, et al., 2009). Findings from this thesis confirm that heightened postural anxiety strengthens the natural attentional bias towards posture and subsequently compromise FRA and increasing the potential risk of falling. Moreover, findings from both studies suggest that although YA experienced increased postural anxiety they remained capable to manage the dual task scenario. Therefore, the capacity for FRA needs to be further investigated among healthy OA to determine additional limitations that may compromise postural stability among OA.

5.4 Clinical Implications

Postural stability is reduced and fall prevalence increases among OA when simultaneously performing a postural and cognitive task (Brown, Shumway-Cook, & Woollacott, 1999; Shumway-Cook & Woollacott, 2000; Woollacott & Shumway-Cook, 2002). From the literature documented in my review of literature, it is clear that falling is multi-faceted. Despite this knowledge, a limited amount of research has investigated balance training while dual tasking. Moreover, as documented by previous research, the attentional strategies employed during a multi-task scenario are dependent upon individual characteristics, postural context, age, and instructional set (Shumway-Cook, Woollacott, et al., 1997). Therefore, it is necessary to design and implement training protocols focusing on dual task abilities in a variety of postural contexts.

Recently, Silsupadol and colleagues (Silsupadol, Lugade, et al., 2009) implemented a balance training protocol that targeted dual task balance performance using three different training strategies. In this training program participants were assigned to either the single-task training group, the dual task training group with variable-priority (focus attention to posture or cognitive performance depending on the instruction provided) or the dual task training group with fixed-priority (focus attention to both tasks equally). The same balance training task was used for all training protocols. The single task training group performed the balance task alone while the dual task group performed a cognitive task according to the instructional sets pertinent to their training protocol. The results indicated that training under variable priority was more effective than fixed priority or single task training however, this training effect did not generalize to the performance of a novel obstacle crossing dual task. Similar training protocols using explicit instructions for task priority have demonstrated similar findings (Silsupadol, Shumway-Cook, et al., 2009) supporting the use of explicit instructions for dual task balance training. Alternatively, Doumas et al. (2009) applied a detailed single and dual task training paradigm consisting of two phases that involved the performance of a cognitive task while standing on a stable or perturbed platform surface (Doumas, et al., 2009). In the first phase participants performed a cognitive task concurrently to a standing task on a fixed or perturbed platform surface. The first phase consisted of five sessions without altering task difficulty. For the second phase, cognitive task difficulty was increased over five more sessions. Results indicated that dual task decrements for the postural and cognitive tasks decreased with practice however, a prioritization of posture was revealed suggesting that OA prioritize posture over the secondary task in challenging contexts.

Results from this thesis are in agreement with findings of Silsupadol et al. (2009) indicating the effectiveness of variable priority instructional sets for dual task training (Silsupadol, Lugade, et al., 2009). Moreover, findings from Doumas and colleagues (2009) revealed the potential for dual task improvement during dual task training on a sway referenced platform (Doumas, et al., 2009). Therefore, it is possible that combining the aspect of instructional used by Silsupadol and colleagues (2009) and the postural challenge by Doumas et al. (2009), may provide an effective training protocol that provide the greatest opportunity for improving the management of multitask scenarios.

5.5 Future Research

Results from this thesis have demonstrated that FRA is compromised among OA in circumstances of increased postural anxiety, yet remains among YA even when postural anxiety is simultaneously presented with a challenge to postural control. This research has presented foundation for future research exploring FRA among OA during combined postural challenge and postural anxiety and possibly among fall fearful OA in circumstance of increased postural anxiety. Understanding how attentional strategies differ among fall fearful OA may allow greater specificity when designing training protocols to limit fall prevalence among this population. The current research in addition presents the possibility of investigating FRA while walking in circumstances of increased postural anxiety. Previous research has demonstrated that gait kinematics differ among YA and OA when postural anxiety is heightened (Brown, Doan, et al., 2006). Moreover, FRA is compromised among balance impaired OA, yet remains among YA and healthy OA while performing a gait and cognitive task concurrently (Siu, et al., 2009). To the best of my knowledge however, research has yet to investigate FRA during circumstances of postural anxiety.

5.6 Limitations

It is necessary to consider a number of limitations when interpreting the results of this thesis. In Experiment 1, the loss of GSC data limited my comparison of physiological arousal. Despite the loss of data, a statistically significant effect of height was achieved with the remaining participant data, further supported by psychological indices of balance confidence and fall anxiety confirmed. Although the majority of data loss was that of OA, which may have weakened the age comparison, previous research employing the surface height model has not reported an age difference in physiological arousal (Brown, Doan, et al., 2006; Brown, Gage, et al., 2002; Brown, Polych, et al., 2006; Brown, Sleik, et al., 2002).

A second limitation relevant to this thesis was the wording and presentation order of the instructional sets. Although the wording of the instructional sets was specific and consistent between experiments and trials, interpretation of the instructions may have differed between participants. Result from this thesis and previous research (Siu, et al., 2008; Siu, et al., 2009; Siu & Woollacott, 2007; Yogev-Seligmann, et al., 2009) however, have demonstrated the effectiveness and necessity of these instructional sets when investigating FRA.

A third limitation that demands attention was the presentation of the NP instruction prior to that of CP or PP may have limited my interpretation of the NP instruction by creating a first trial effect. The purpose of the performing the NP instruction first was to acquire an accurate assessment of natural unbiased task priority. Therefore, it was necessary for participants to perform the NP instruction to avoid biasing by the CP and PP instructions.

5.7 Conclusion

The purpose of this thesis was to investigate the influence of postural anxiety on the ability to flexibly allocate attention among YA and OA. During circumstances of heightened postural anxiety, OA did not alter cognitive or postural performance according to instructional set. It seems that postural anxiety strengthened the natural attentional bias to postural control, and subsequently compromised the capacity for FRA. Conversely, during heightened postural anxiety the capacity for FRA remained among YA. Even when a challenge to posture was imposed concurrent to postural anxiety, YA maintained the ability to alter cognitive performance according to instructional set without compromising postural stability. I have interpreted these results to indicate that

YA have the attentional capacity to automatically prioritize the postural task while remaining capable of altering cognitive performance according to instructional set.

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