DOES POSTURAL THREAT ALTER THE ROLE OF COGNITION FOR POSTURAL CONTROL?

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DEDICATION

I would like to dedicate this thesis to my family and friends who have supported me throughout its conception.

ABSTRACT

Cognitive demands for postural control in younger and older adults were examined under conditions of postural threat. Age-related differences emerged in the distribution of attention for postural control in conditions of postural threat. Specifically, postural compensations were implemented to reduce cognitive demands for postural control. In addition, it was determined that the effect of performing a secondary cognitive task on postural control was altered when the potential consequences of instability were increased. Younger adults were found to maintain postural control and improve secondary task performance in conditions of increased threat whereas postural control in older adults improved at the expense of secondary task performance. In older adults, postural control may be prioritized under conditions that increase arousal and the consequences of imbalance. These findings have implications for reducing falls in elderly populations, as they reveal that the ability to adequately perform concurrent tasks is compromised when environmental factors threaten balance in elderly populations.

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GENERAL INTRODUCTION

The purpose of this thesis was to examine the effects of postural threat on postural control and associated cognitive demands in younger and older adults. The format of the thesis includes a detailed introduction that presents relevant concepts of the biomechanical, sensory, and cognitive contributions to the maintenance of postural control. In addition, changes in postural control, as a result of aging or arousal from conditions of environmental threat, will be addressed. Two separate and complete studies are presented. The first study examines the effects of postural threat on the allocation of attention for postural control in younger and older adults. The second study examines how postural control is altered in younger and older adults by a secondary task in conditions of postural threat. In addition, the prioritization of postural control over secondary task performance is examined in conditions of increased postural threat in the second paper. Finally, a general discussion addresses the findings obtained and their contributions to the current literature. In addition, the practical implications to daily activities in younger and older adults are considered with respect to the effects of arousal and anxiety on postural control.

POSTURAL CONTROL

Postural control is the continuous process of controlling the body's position in space to preserve an upright and stable posture (Shumway-Cook & Woollacott, 2001). Stability is achieved when the mass of the body is maintained within the limits of the supporting structures on the ground (Winter, 1995). To achieve stability, information about the environment must be integrated with information regarding the current state of the body. This information, both internal and external to the body, is obtained through the visual, somatosensory, and vestibular systems and integrated by the Central Nervous System (CNS) to provide appropriate motor output to ensure that equilibrium is maintained. Dysequilibrium, or a loss of balance, occurs if information from sensory sources is altered and/or if the body experiences a disturbance (Winter, 1995).

It is known that aging leads to deterioration in the visual, somatosensory and vestibular systems necessary for postural control (Alexander, 1994). Consequently, many older adults are at a risk of falling. Falling is a prevalent occurrence in the elderly in North America, as 30% of those over the age of 65 experiences a fall each year (King & Tinetti, 1995). The outcome from a fall can be severe and debilitating. In fact, it has been reported that 66% of injury related deaths in those over the age of 75 are the result of a fall (Hindmarsh & Estes, 1989). Furthermore, those who fall often experience a fear of falling, or an intense anxiety regarding the possibility of another fall episode. Fear of falling can be so debilitating that it leads to a downward spiral of reduced engagement in physical and social activities and an eventual loss of independence (King & Tinetti, 1995). The consequences of falls also extend beyond the individual and into the community; in fact, the consequences of falls also stress health care systems. Almost 40% of those who fall are admitted to a hospital and 50% of those admitted return to a home care setting (Sattin et al., 1990). If the factors involved in precipitating a fall are identified, it may be possible to develop fall prevention programs to address the needs of individuals and thus also reduce the deleterious social and medical consequences of this problem.

Identifying those who may be at risk for falling requires an assessment of individual balance ability. These assessments can be performed in the clinic or in the laboratory. Clinical assessments of balance provide practitioners and therapists with an indication of the capacity of the postural control system. This can be accomplished with simple tasks such as standing up from a seated position (Mourey, Grishin, d'Athis, Pozzo, & Stapley, 2000) or reaching for an object as far forward as possible (Duncan, Weiner, Chandler, & Studenski, 1990). Further, clinical assessment techniques, such as the Berg Balance Scale (Berg, Wood-Dauphinee, Williams, & Maki, 1992) and the "Get up and Go" test (Mathias, 1986) have been developed to provide clinical practitioners with a standardized method of assessing balance. These tests determine participant's performance on tasks of daily living that challenge balance and postural control. However, because changes in the function of postural control mechanisms are often too subtle to detect with clinical techniques, balance often needs to be assessed more rigorously using laboratory equipment (Andres & Anderson, 1980). Laboratory postural control assessments are based on principles of physics and offer a more stringent analysis of postural control capacity. Before a description of laboratory-based assessments of postural control is presented, a discussion of the biomechanics of postural control is warranted.

BIOMECHANICS AND NEURAL ORGANIZATION OF POSTURAL CONTROL

The principles of physics dictate that the net location of the mass of the body, conceptualized as the Centre of Mass (COM), must be maintained within the limits of the body's Base of Support (BOS; i.e., feet) for equilibrium to be preserved. Humans are inherently unstable because 2/3 of the mass of the body is located 2/3 above the BOS. In addition, gravity acts continuously to accelerate the mass of the body toward the ground (Winter, 1995). Thus, even though an individual is attempting to stand as still as possible, small fluctuations in the COM position, that result from gravitational forces acting on the body, continue to occur. These natural fluctuations can be observed as a small amount of movement around the ankle joint and this movement is referred to as spontaneous postural sway. When a disturbance occurs, forces are generated around the joints by the muscles of the legs and trunk (i.e., muscle torques) to prevent a loss of balance. The forces exerted against the ground as a result of applying muscle torques around the joints can be measured. The net location of the vertical forces applied to the ground is referred to as the Centre of Pressure (COP; (Winter, Patla, & Frank, 1990). Changes in the mean position of the mass of the body is indicated by movement of the COM; movement of the COP indicates changes in the net location of the forces acting on the ground generated by the body to control the COM. Movement of the COP is highly correlated with COM and thus, can be interpreted as an indicator of the movement of the COM (Eng & Winter, 1993).

The dynamic relationship between COM and COP is fundamental to understanding postural control during quiet stance. Figure 1 illustrates an example of COM and COP during quiet standing in a young adult. During upright stance, the body has been modeled as an inverted pendulum that constantly needs to be controlled to prevent it from falling over due to gravitational forces. The COP moves beyond the COM as it moves anterior (a) to push it posterior to maintain the COM within the BOS. Once the COM begins to move posterior (b) the COP must now get behind the COM to bring it anterior. The COP in the medial/lateral directions controls the COM similarly. Thus, the relationship between COP and COM can be conceptualized in an analogy with a shepard keeping his flock. The shepard (CNS) continuously directs the sheepdog (COP) to control the sheep (COM) that are always trying to escape the confines of the range (BOS).

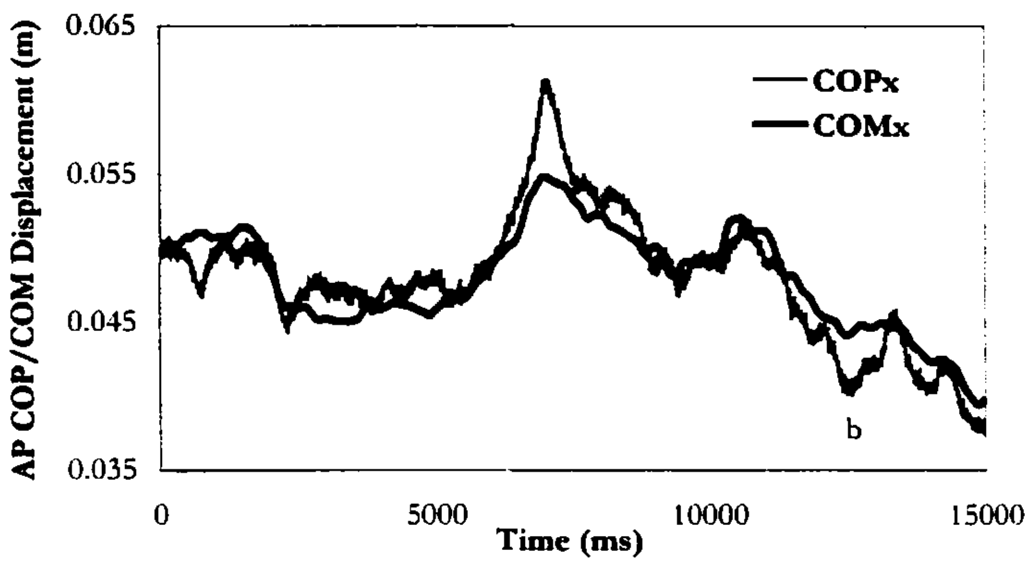

Figure 1 The relationship between the COP and COM in the Anterior/Posterior (AP) direction of a 21 year old female participant during 15s of feet together, eyes open quiet standing. The COP moves anteriorally to push the COM posteriorally (a) and moves posteriorally to push the COM anteriorally (b) (unpublished data).

In the laboratory, spontaneous postural sway is the most commonly measured construct of postural control. Sheldon (1963) devised one of the earliest laboratory techniques to measure spontaneous postural sway. A triangular apparatus with a pencil and string extending to the ground was placed, on the participant's head and shoulders. Participants were instructed to stand as still as possible while the pencil traced the spontaneous postural sway onto a piece of graph paper. More recently, postural sway has been measured using a forceplate. A forceplate is a solid platform instrumented with force transducers that measure the magnitude of resultant forces applied to its surface in each of the anterior/posterior, medial/lateral, and vertical directions. A forceplate will indicate the magnitude and polarity of the moment of force about each directional axis. When an individual stands on a forceplate the net location of the application of vertical force, as well as the mass and polarity of torques, are measured. These measures provide the information for the calculation of COP in the anterior/posterior and medial/lateral dimensions as follows:

COPx = My/Fz (anterior/posterior)

COPy = Mx/Fz (medial/lateral) where M = Moment and F = Force

Fluctuations in the polarity and magnitude of the torques applied to the forceplate reflect subtle differences in body position such as those that occur during quiet standing. Variables indicating movement of COP, such as variability, range of excursion, area, and mean position, are often calculated to provide an indication of postural control during quiet stance or in situations where balance is challenged (i.e., altering sensory information like depriving vision (Winter et al., 1990).

Although quiet stance provides an important indication of postural control abilities, the greatest challenge for the postural control system occurs following a sudden unexpected disturbance. External disturbances, such as a slip on an icy sidewalk or an unexpected jostle, require reactive postural adjustments to maintain the COM within the BOS. Responses to unexpected external disturbances reflect the greatest challenge to postural control because postural accommodations occur after the disturbance has affected the COM (Winter, Patla, & Frank, 1990). To prevent a fall, appropriate reactive and proactive responses must be selected and implemented with enough time to recover balance. Thus, to direct muscles to provide the necessary forces required to maintain the COM within the limits of the BOS, the CNS must make rapid and organized postural adjustments (Winter, 1995). Thus, balance ability is best assessed by determining an individual's capacity to recover from an external perturbation (Nashner, 1976). Various techniques can be used in the laboratory to assess balance. For example, perturbations to postural control can be applied by moving the support surface under the participants feet (Nashner, 1983) or by disrupting equilibrium with an external force (Brown & Frank, 1997).

Based on the work of Nashner and colleagues (Nashner, 1976; Nashner, Woollacott, & Tuma, 1979; Woollacott, Shumway-Cook, & Nashner, 1986), several movement solutions have been identified for the recovery of upright postural equilibrium. Recovering equilibrium is accomplished by utilizing one of two distinct groups of response strategies. Either the BOS can be maintained (i.e., feet are kept in place) or it can be modified to accommodate the change in the position of the COM. When keeping the feet in place an "ankle" or "hip" strategy can be employed. The ankle strategy applies a torque around the ankle joint to control the COM and is accomplished through muscle torque generated by the plantarflexors and dorsiflexors of the leg. Forces generated around the ankle joint function to move the COM back within the limits of the BOS (Winter, 1995). In response to a larger perturbation an individual may adopt a hip strategy that produces motion at the hips to control the motion of the COM (Horak & Nashner, 1986). However, in some instances the BOS must accommodate the change in the COM position and a step, hop, or grab is used. The stepping or hopping strategy is typically employed when the disturbance is large enough that the BOS must be moved to encompass the COM (Shumway-Cook & Woollacott, 2001). If possible, a grab is used to recover balance by using an outside object, such as a railing or wall, to increase the BOS (Horak et al., 1986). To make the appropriate response to recover equilibrium, the CNS must determine how the COM is being changed and then initiate the appropriate groups of muscles in an approach to produce the optimal strategy.

The CNS activates groups of muscles together to regulate postural control and initiate recovery strategies. The muscle groups selected to achieve a postural task are referred to as postural synergies (Latash, 1998). In several experiments, Nashner and colleagues (Nashner et al., 1979; Nashner, 1983; Horak et al., 1986) determined that the CNS organises specific synergistic arrangements of muscles to generate the necessary postural adjustments to recover from a particular perturbation. To examine adjustments made by the CNS in response to different perturbations, Nashner, Woollacott, and Tuma (1979) recorded muscle activity when participants had their posture disturbed by moving two forceplates in four ways: 1) vertical displacement, 2) reciprocal displacement (vertical displacement of one forceplate at a time), 3) horizontal translation, 4) rotation with the ankle joint. These authors demonstrated that in response to a perturbation, postural synergies were highly organized and specific to the type of movement needed to recover from the perturbation. Nashner and colleagues hypothesise that there are limited number of programmed responses that can be utilised to recover from a postural disturbance. These postural synergies appear to be highly organized and designed to recover postural control from specific perturbations. However, this experiment also revealed that when testing conditions were unexpectedly presented, the initial synergistic responses to the perturbation were inappropriate. After 3 to 5 successive trials, muscle synergies were altered to recover postural stability appropriately. The work of Nashner and colleagues (Nashner et al., 1979; Horak et al., 1986) reveals that although postural synergies appear to be pre-programmed, synergies can be altered to accommodate changes in the type of perturbation or environmental condition.

The strategy that is used to recover postural control depends on several factors. Typically, if a perturbation is relatively small and the BOS is stable and large an ankle strategy is used. However, if a perturbation requires more rapid postural adjustments, a hip strategy may be implemented. Finally, if a disturbance is large enough that the COM has exceeded the BOS, a stepping strategy can be used to move the BOS to encapsulate the COM. Thus, the severity of the disturbance that is imposed on the body can alter the strategy that is used to recover postural control. Furthermore, the CNS plays a role in determining what strategy is to be used to maintain equilibrium by integrating information about the environment. Environmental factors, such as changes to the support surface, can also alter the postural strategies that are implemented to recover postural control. For instance, slippery surfaces that do not provide enough friction to sustain the sheer forces involved in a hip strategy may require the use of an ankle strategy instead (Horak et al., 1986). Horak and Nashner examined recovery from a postural perturbation on surfaces that provided a normal and a short BOS (9cm long). Results indicated that in the short BOS condition most participants shifted from the ankle strategy they used in the normal condition to a hip strategy after 5 - 15 practice trials. When the subjects were subsequently tested in the normal condition they returned to using an ankle strategy after 3 - 6 trials. This experiment reveals that the CNS incorporates sensory information about the environment to determine the most appropriate strategy for recovery of postural control after a perturbation.

SENSORY AND MOTOR PROCESSES REGULATING POSTURAL CONTROL

According to the Systems Approach, balance is maintained by different systems that act co-operatively to anticipate or react to changes in the environment and positions of the body (Woollacott & Shumway-Cook, 1990). The CNS acts to integrate sensory information about the environment and the body and to respond to perceived changes in equilibrium (Shumway-Cook & Horak, 1986). Visual, somatosensory, and vestibular information is processed to determine changes in the body and environment; the musculoskeletal system is involved in executing the necessary postural strategies to maintain balance (Nashner, 1976).

ROLE OF SENSORY INPUT IN POSTURAL CONTROL

Vision

The CNS relies on different types of visual information for postural control (Nashner, Black, & Wall, 1982). The visual system is responsible for perceiving the location of the body in relationship to objects in the environment and to itself (Lee & Young, 1986). Seeing objects clearly, or visual acuity, is important in discriminating uneven surfaces, obstacles, and slopes in walking surfaces (Sekuler & Hutman, 1980). When negotiating obstacles or uneven terrain during locomotion, visual input is especially important in controlling how both the leading and the trailing limb is lifted and placed to clear the oncoming object (Patla, Rietdyk, Martin, & Prentice, 1996). When vision is reduced, the likelihood of tripping or stumbling will increase, leading to a greater risk of falling. Vision is also important in giving feedback, such as the speed that the body is moving at when in motion. In addition, visual flow is important as a reference to where the body is with respect to the environment (Shumway-Cook & Woollacott, 2001).

To demonstrate the importance of vision in postural control Lee and colleagues (Lee & Young, 1986; Lee & Aronson, 1974) asked participants to stand in an enclosure with a fixed floor and moveable walls. These authors found that participants swayed forward when the walls (i.e., the visual reference) moved forward. Anterior movement of the body occurred to compensate for the perceived posterior change in the body's position. Therefore, vision was demonstrated to be essential in discriminating changes in the position of the body and also for providing the CNS with information to compensate for the perceived change. Other experiments have examined the role of specific components of vision in postural control. The role of central vision and peripheral vision in postural control was examined by Manchester and colleagues (1989). In this work, visual input was manipulated with goggles to create three testing conditions: a) no peripheral vision b) no central vision c) no vision. When compared with the eyes open control condition, these data indicated that the absence of peripheral vision impaired balance more than the loss of central vision. Consequently, peripheral vision has been shown to be important in determining the position of the body relative to objects in the environment, and is essential in postural control (Manchester et al., 1989).

Somatosensory

The somatosensory system is comprised of peripheral receptors that perceive changes in the position of joints and muscles as well as cutaneous receptors that perceive changes from the external environment (Shumway-Cook & Woollacott, 2001). The receptors of the somatosensory system determine the position of the body relative to supporting surfaces and the position and orientation of body segments. External skin receptors are involved in detecting differences in support surfaces (Kenshalo, 1979), such as when negotiating uneven terrain or detecting surfaces like slippery sidewalks. Experiments that alter support surfaces, for example, when standing on thick foam, have been shown to reduce postural control because the quality of somatosensory information is altered (Nashner et al., 1982). The joints and muscles contain proprioceptive sensors that are important in determining orientation and movement of body segments as well as loads on the musculoskeletal system (Latash, 1998). Woollacott, Shumway-Cook, and Nashner (1986) altered somatosensory input by using a technique that moved the surface of the platform and/or visual enclosure to match the sway of the participant; a technique that effectively eliminates sway-related somatosensory and/or visual information (Nashner et al., 1982; Nashner, 1976). These authors determined that participants had more postural sway when somatosensory information was altered or misleading and the most amount of sway when both visual and somatosensory information were altered.

Vestibular

The vestibular system is essential in determining the position and movement of the head in space and is particularly important when deconstructing conflicting visual and somatosensory information (Nashner et al., 1982). Nashner and colleagues found that postural control was significantly reduced when visual and somatosensory information was altered in participants with known vestibular deficits compared to participants who had no vestibular problems. The results from this study indicate that the vestibular system has an important role in compensating for altered or misleading visual and somatosensory information. The nerve fibres that innervate the vestibular system are very sensitive so that even very small accelerations in the body can be detected. In addition, the vestibular system is important in mediating eye movements in response to changes in body and head position and thus, allows for the stabilization of vision on a particular object while the body is in motion (Latash, 1998). Individuals with impaired vestibular function often report vertigo and dizziness and find it difficult to maintain equilibrium (Rosenhall & Rubin, 1975). Allum and colleagues (1988) have demonstrated that individuals with vestibular deficits have dysfunctional postural control responses compared to those with intact vestibular systems because the vestibular system does not provide appropriate feedback about the body's position. In particular, patients with vestibular abnormalities were found to make postural responses that were insufficient to recover from the magnitude of the perturbation.

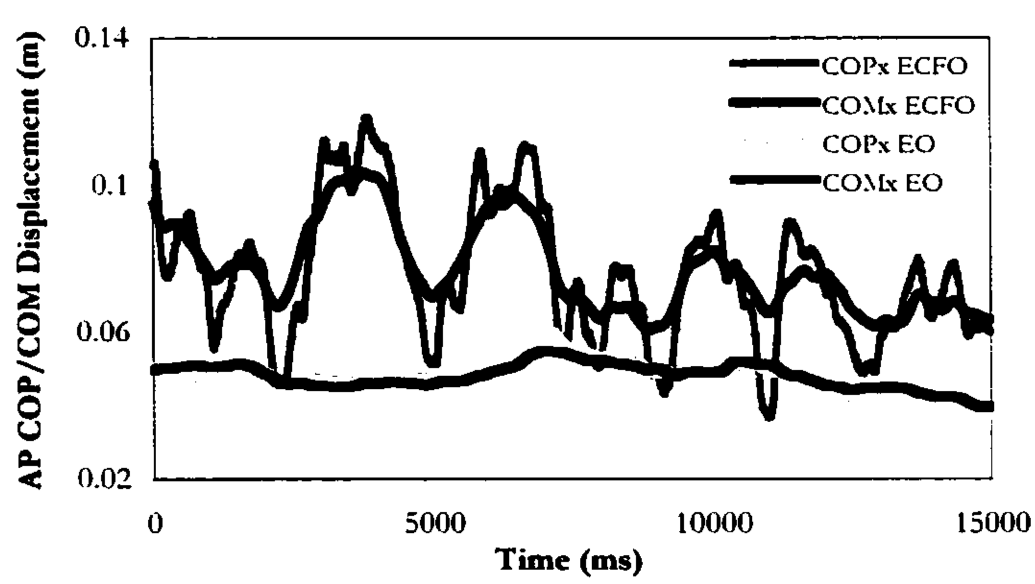

Figure 2 The relationship between the COP and COM in the Anterior/Posterior (AP) direction of a 21 year old female participant during 15 s of feet together, eyes closed quiet standing on a foam surface (ECFO) versus quiet standing with eyes-open. Hatched lines represent eyes-open conditions (EO). Notice that displacement and the variability of displacement significantly increases in both COM and COP in the ECFO condition compared to the EO condition (unpublished data).

Compounding Sensory Deficits

If the quality of the information from multiple sensory systems is disrupted or misleading, it can have a compound effect on postural control (see Figure 2). For instance, Lord and Menz (2000) found that a loss of visual input was more disruptive to postural control when proprioceptive input was also compromised. Furthermore, Woollacott and colleagues (1986) found that the combined loss of somatosensory and visual information altered postural control more severely than visual and vestibular and somatosensory and visual combinations of information loss. Often the CNS will compensate for altered somatosensory input with visual information. However, when both visual and somatosensory information is lost, the vestibular system is often used to determine the body's position in space to maintain equilibrium (Nashner et al., 1982). The results from these studies reveal that effective postural control can be maintained when the input from one sensory system is reduced, but the loss of information from more than one sensory component can have dramatic effects on postural control.

ROLE OF MUSCULOSKELETAL SYSTEM IN POSTURAL CONTROL

The skeletal system provides a framework for the body's muscles. Muscles generate the necessary forces that keep the body upright (Whipple, Wolfson, & Amerman, 1987). Misalignment or abnormalities of the musculoskeletal system can affect postural control. For instance a stooped posture moves the COM further forward in the BOS and more effort must be made by the musculature to maintain equilibrium. Similarly, hemiplegia can create instability by shifting the COM laterally (Shumway-Cook & Woollacott, 2001). Deficits in muscular strength, endurance, and flexibility can contribute to instability because the ability to use certain strategies become limited by inefficiencies in the musculoskeletal system (Daubney & Culham, 1999). Therefore, exercises that are designed to strengthen muscular strength and develop range of motion are often used to rehabilitate balance and gait disorders (Lord, Ward, Williams, & Strudwick, 1995).

COGNITION AND POSTURAL CONTROL

Recently, research has determined that postural control is not an automatic process; instead, postural control requires cognitive processing (Lajoie, Teasdale, Bard, & Fleury, 1993). This finding has led to investigations that have assessed the cognitive demands for postural control across tasks of varying difficulty (Teasdale, Bard, LaRue, & Fleury, 1993; Lajoie, Teasdale, Bard, & Fleury, 1996a) as well as the allocation of attentional demands to postural control across different contexts (Brown, Shumway-Cook, & Woollacott, 1999; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). The underlying basis for work in cognition and postural control is based on theoretical applications of attention: a) there is a limited capacity of attentional resources available for completing certain tasks b) the allocation of attentional resources is determined by environmental and situational factors, and can be divided between different tasks (Kahneman, 1973). Thus, if the CNS is unable to allocate sufficient resources to processes involved in maintaining equilibrium a loss of balance can occur.

To assess the cognitive demands for different postural tasks, a dual-task paradigm is typically used (Abernethy, 1988). The dual-task methodology requires performance of a postural task, such as standing, while simultaneously performing a secondary task. The secondary task is typically a discrete probe-reaction-time (PRT) task that requires individuals to respond to an auditory or visual cue as quickly as possible (Abernethy, 1988). A secondary task can also consist of performing continuous cognitively demanding tasks such as counting backwards in threes, random digit generation, or performing a spatial memory task (e.g. Maylor & Wing, 1996). Results from discrete dual-task tests reflect the attentional capacity allocated for perceiving stimuli at the moment of stimulus presentation whereas a continuous task determines temporal changes in attention necessary for performing both tasks (Abernethy, 1988).

Three basic assumptions regarding models of cognitive resources are necessary when applying the dual-task methodology to postural control research: a) the CNS has a limited capacity that is available b) a proportion of the resources available are needed to perform specific tasks c) if the central processing capacity is less than that needed to perform two concurrent tasks, the performance in one task will decline. Thus, a change in performance of a secondary task reflects increased demands placed on the CNS by the primary task (Abernethy, 1988). However, conditions that require an abundance of cognitive resources may result in diminished performance in both tasks (Lindenberger, Marsiske, & Baltes, 2000).

A demanding primary task may leave fewer resources available for the performance of a secondary task (Kahneman, 1973). Following the assumptions regarding models of cognitive resources, a decrement in the performance of a secondary task will be observed. However, if more attentional resources are attributed to the secondary task, performance on the postural task may decline. For some individuals, the need to perform one task may outweigh that of another. For example, conversation is often interrupted when a person is performing a difficult task. The "posture-first" hypothesis (Shumway-Cook et al., 1997; Marsh & Geel, 2000; Kerr, Condon, & McDonald, 1985) suggests that in circumstances where instability is a threat, postural performance will take precedence over other tasks. The importance of postural control may be illustrated by disruptions in a conversation by an individual who is walking across an icy section of sidewalk. The task of talking gives way to the demands of walking on a slippery surface without falling.

ATTENTIONAL DEMANDS FOR POSTURAL CONTROL

Research using the dual-task methodology has determined that more complex postural tasks, such as walking, require greater cognitive resources than less challenging tasks like sitting (Teasdale et al., 1993). Lajoie and colleagues (1993) asked participants to perform a probe-RT task in 4 conditions of increased postural complexity: 1) sitting, 2) standing with a normal BOS (feet comfortably apart), 3) standing with a narrow BOS (tandem Romberg stance), and 4) walking. Changes in performance of the RT task were interpreted to reflect differences in the cognitive demands associated with the postural task. Results revealed that greater attentional demands (indicated by longer RT) were required as the complexity of the postural task changed. Although probe-reaction time tasks are useful in indicating the attentional demands for a particular task, tests that distract attention away from postural control have also been important in explaining the role of prioritization in postural control.

Effects of Performing a Secondary Task on Postural Control

Research has shown that distracting an individual with a cognitive task can alter postural control. Kerr and colleagues examined the interaction of introducing a cognitive task on postural control (Kerr et al., 1985). These authors used Brook's spatial and non-spatial memory tasks (Brooks, 1967) as a secondary task to interfere with postural control. Interference between the spatial task and the postural task was expected because both tasks compete for the same resources involved in perceiving and visualizing information (Finke & Kosslyn, 1980). Results indicated that postural control did not change with the simultaneous performance of either type of secondary task. However, performance on the spatial task was significantly reduced when participants were standing when compared to when they were sitting. Performance of the non-spatial task was not altered in any of the conditions. These findings indicated a prioritization of postural control over spatial task performance. Furthermore, these findings confirm that postural control shares similar neural mechanisms with those needed for completing a visual/spatial task (Kerr et al., 1985).

Although the research by Kerr et al. (1985) indicates that postural control is preserved when the CNS is loaded from a secondary task, recent research has provided contrasting results (Maylor & Wing, 1996). Maylor and Wing examined the effects of introducing a secondary task on postural control in middle-aged and older adults. These authors found that the effects of introducing a secondary task on postural control depended on the age of the subject. In particular, it was found that postural control, and not cognitive performance, was altered in older adults when a secondary task was introduced. Interestingly, this finding emerged when participants were asked to perform the spatial memory and digit subtraction tasks. Both of these tasks are argued to rely on visual/spatial cognitive processes. Therefore, it appears that the prioritization of postural control over task performance may be age and task dependent.

Cognitive performance and the availability of attentional resources are important components in postural control. Thus, one approach in the pursuit to reduce falls is to understand the role of cognitive demands for postural control and the effect that different situations and tasks have on the attentional resources necessary for postural control. Furthermore, because prioritization of postural control over secondary task performance may be age related, it is important to determine how younger and older adults prioritize the allocation of attention in different conditions. The implications of these findings may be particularly important for older adults, because a fall may occur if insufficient attentional resources are available for postural control.

Research so far has explained how the CNS integrates sensory information and controls the musculoskeletal system to maintain postural control. Studies such as those conducted by Nashner and colleagues (1982) and Woollacott and colleagues (Woollacott et al., 1986; Manchester et al., 1989; Shumway-Cook & Woollacott, 2000) have demonstrated how postural control changes when sensory information is altered. In addition, the availability of cognitive resources has also been implicated as a necessary component of postural control (Shumway-Cook et al., 2000; Brown et al., 1999; Teasdale et al., 1993; Lajoie, Teasdale, Bard, & Fleury, 1996b). It has been firmly established that age-related functional decline occurs in the sensory systems for postural control (Black, et al., 1993). In addition, it is known that age-related changes in sensory function have a negative impact on postural control (Woollacott, 1989) and recovery from postural perturbations in older adults (Maki & McIlroy, 1996). Thus, to lessen the rate of falls in older adults, deficits in each system must be identified so that programs can be implemented to reduce debilitating falls that can compromise the quality of life of older adults (King et al., 1995).

AGING AND POSTURAL CONTROL

Aging is a heterogeneous process that can profoundly affect an individual's ability to maintain equilibrium in many different ways (Shumway-Cook & Woollacott, 2001). Serious neurological insults, such as cerebral vascular accidents, head injuries, and degenerative neuropathies, often cause impaired postural control in older adults (Hill & Vandervoort, 1996; Keenan, Perry, & Jordan, 1984; Morris, Rubin, Morris, & Mandel, 1987; Berhardt, Ellis, Denisenko, & Hill, 1998; Mesure, Pouget, & Amblard, 1999; Bronstein, Brandt, & Woollacott, 1996). In fact, Black and colleagues (1993) have identified 27 different neurological disorders that can impair gait and balance. However, compared to younger adults, even healthy older adults who have not suffered from serious neurological or physical disruptions have deteriorated postural control. Indeed, a great deal of research has established that older adults are less stable than younger adults (Maki et al., 1996; Woollacott, 1989; Hytonen, Pykko, Aaalto, & Starck, 1993; Woollacott et al., 1986). This research is supported by reports that between 30-40% of those over the age 65 experience a fall every year (Vellas, Wayne, Garry, & Baumgartner, 1998). Recent research by Toupet and colleagues (Toupet, Gagey, & Heuschen, 1992) revealed that postural sway increased with each decade in screened individuals aged 40 to 80. In a series of studies, Maki and colleagues (Maki, Holliday, & Fernie, 1990; Maki et al., 1996; Maki, 1997) determined that compared to younger adults, older adults sway more when maintaining a static position, are less effective in recovering from an external perturbation, and are more unstable when walking. Thus with age, significant changes in the function of postural control mechanisms are observed.

AGE-RELATED CHANGES IN THE MUSCULOSKELETAL SYSTEM

Muscle strength and endurance is important for recovery from postural perturbations and essential in maintaining a stable upright stance (Whipple et al., 1987). Research has shown that quality of life is compromised in those who do not possess sufficient muscle strength and endurance to perform daily activities (Skelton, Young, Greig, & Malbut, 1995; Schenkman, Hughes, Samsa, & Studenski, 1996; Rantanen et al., 1999). Muscle strength has been shown to dramatically decline with age (Aniansson, Grimby, Hedberg, Rudgren, & Sperling, 1978). This age-related decline in muscle strength may have an adverse effect on postural control. For instance, Whipple and colleagues (1987) examined leg strength in elderly participants living in a nursing home. These authors found that individuals who had a history of falls had 64% less leg strength than their non-falling cohorts. Research has shown that there is a steady decrease in motor neurons in the CNS with age, and by the 6th and 7th decades roughly two-thirds of some motor neurons disappear (Scheibel, 1985). Reduced motor neurons may slow the transmission of responses to the musculoskeletal system thus, altering the effectiveness of anticipatory and reactive postural control strategies (Maki et al., 1996b).

Insufficient muscle strength, endurance, musculoskeletal flexibility, and reduced motor neuron function are contributing factors to fall risk in elderly populations (Chu et al., 1999; Woollacott et al., 1990; Foster, Hume, Byrnes, Dickinson, & Chatfield, 1989). In response to these findings, research has successfully determined that postural control can be improved by implementing programs that improve musculoskeletal strength, endurance and flexibility (Skelton et al., 1995; Fiatarone et al., 1990). These programs can improve quality of life by improving mobility and postural stability to lessening the risk factors associated with falls (Lord, Ward, & Williams, 1996; Rubenstein et al., 2000).

In a series of studies Lord and colleagues (Lord & Castell, 1994; Lord et al., 1996) asked adults of the age over 50 years to participate in exercise programs lasting 1 hour twice a week. Exercise programs consisted of walking, modified aerobics, group games, and strength training activities. Compared to controls, participants were found to have improved balance, muscle strength, and gait velocity, and faster reaction time. Furthermore, studies that have used Tai Chi (Wolf et al., 1996; Lan, Lai, Chen, & Wong, 1998), water exercise (Shaw & Snow, 1998; Simmons & Hansen, 1996), and Swiss Balls (Brown, Sleik, Polych, & Bocksnick, Submitted) have also found beneficial effects on overall fitness and postural control in older adults. Thus, the effects of age-related changes to the musculoskeletal system may be improved through a variety of exercise regimes in order to help reduce the risk of falls in older adults.

AGE-RELATED CHANGES IN SENSORY SYSTEMS

Vision

It has been well documented that the quality of visual sensory information is altered by the aging process (Koroknay, 1995). With age, visual acuity is often compromised due to cataracts, scotomas, and macular degeneration and peripheral vision is reduced by degenerative retinal disease (Naeyaert, 1990). The ability to focus at distances and see in low light conditions is also reduced in older adults (Duthie, 1989). Because acuity is important for detecting differences in the environment (Sekuler et al., 1980), older adults may be at a greater risk of tripping on obstacles. Thus, there are several age-related changes to vision that may alter the maintenance of postural control.

Research that has manipulated visual input has revealed that older adults are more susceptible to altered visual information than younger adults (Manchester et al., 1989). Subsequent studies have determined that postural stability in older adults is significantly compromised by eyes closed conditions compared to younger adults, especially in postural tasks where proprioceptive feedback is altered (Woollacott et al., 1990; Woollacott, 2000; Teasdale, Stelmach, Breunig, & Meeuwsen, 1991; Turano, Rubin, Herdman, Chee, & Fried, 1994). Many of these age-related visual deteriorations can contribute to a greater risk of falling in older adults.

Somatosensory

The importance of proprioceptive feedback in postural control has been well established (Latash, 1998). Cutaneous and proprioceptive receptors are less sensitive in older adults and therefore the ability to perceive the position of extremities and joints is compromised (Kenshalo, 1979; Potvin, Syndulko, Tourtellotte, Lemmon, & Potvin, 1980; Skinner, Barrack, & Cook, 1984). Older adults may be at a greater risk of falling because they are unable to perceive hazards such as slippery or uneven surfaces. A study by Potvin and colleagues (Potvin et al., 1980) examined neurologic function in 61 participants aged 20-80. The authors determined that reduced vibration sensitivity was one of the more prominent neurologic factors that declined with age. Recent work by McChesney and Woollacott (2000) has also revealed that older adults who had poor joint position sense had significantly greater measures of COP variability and displacement compared to older adults who had normal joint position sense. These findings indicate that reduced somatosensory and proprioceptive functioning can negatively affect postural control in older adults.

Vestibular

The vestibular system is important in modulating postural control when visual and somatosensory information is insufficient or conflicting (Nashner et al., 1982). However, older adults lose almost 40% of vestibular hair and related nerve cells by the 7^{th} decade of life (Sloane, Baloh, & Honrubia, 1989). Many older adults experience dizziness and dysequilibrium as a result of reduced vestibular function (Rosenhall et al., 1975). Because the vestibular system is used as a global reference of the body's position in space, changes to the position of the body are often not accurately detected or interpreted in older adults. Thus, similar to individuals with vestibular neuropathies, older adults may underestimate postural responses to a perturbation (Allum & Pfaltz, 1985). Allum and Pfaltz compared postural recovery strategies in participants with and without vestibular deficits. These authors found that participants with reduced vestibular function were more likely to fall when asked to tilt their head backward. The dysfunctional vestibular system was unable to appropriately determine the changes in the body's position and thus, the CNS was unable to make the sufficient compensatory adjustments to recover postural control.

Compounded Sensory Deficits

Aging is a multidimensional process that involves the degradation of neuromuscular, musculoskeletal, and sensory systems. Although reduced function in one system alone may not dramatically affect postural control, the combined deterioration in one or more of these systems can have a cumulative effect on the maintenance of equilibrium (Shumway-Cook & Woollacott, 2001). To compound the effects of musculoskeletal and sensory system degenerations, postural control in older adults may also be compromised by age-related changes to cognitive capabilities. Age-related cognitive changes such as slowed information processing or reduced attentional capacities may alter the effectiveness of the CNS to compensate for sensory dysfunction and maintain postural control in older adults (Teasdale et al., 1993). Because older adults are more susceptible to cognitive decline than younger adults (Keefover, 1998), recent research has focused on age-related differences in cognitive processes involved in postural control.

COGNITIVE DEMANDS FOR POSTURAL CONTROL IN OLDER ADULTS

Recently, increasing research has been devoted to understanding the cognitive demands for postural control in older adults. Older adults are less capable than younger adults of dividing their attention between two concurrent tasks (Vanneste & Pouthas, 1999). The diminished ability to divide attention may be the product of an overall reduction in attentional capacities in older adults (Craik & Byrd, 1982) and/or slowed information processing capabilities (Salthouse, Fristoe, Linewater, & Coon, 1995). Thus, older adults may be at a greater risk of falling when dividing their attention between a postural task and a secondary cognitive task, especially if the combined demands of the task exceed the available cognitive resources. For example, when walking down stairs and talking to a friend, an older adult may be at a greater risk of tripping and falling because there may be insufficient resources to adequately attend to both tasks.

Cognitive or attentional demands are the resources needed to perform specific tasks (Kahneman, 1973). Recent research by Lajoie and colleagues (1996a; 1996b) has determined that the cognitive demands necessary for postural control are greater for older adults compared to younger adults. Teasdale and colleagues (Teasdale et al., 1993) examined the cognitive demands for postural control in younger and older adults. Participants were asked to perform a probe-reaction-time task in four postural conditions that altered visual and somatosensory information. In all conditions older adults were found to have longer reaction times, indicating that the cognitive capacities of older adults are slowed compared to younger adults. Furthermore, older adults required more cognitive demands in the no-vision conditions whereas younger adults showed little differentiation. Thus, in addition to age-related changes in processing speed, older adults require greater cognitive resources for postural control when sensory information is altered. According to Stelmach and Worringham (1985), delays in reaction time to postural disturbances could significantly affect an individual's ability to recover from a loss of balance. Thus, changes in the attentional demands for postural control can have serious implications for fall risk in the elderly.

EFFECTS OF INTRODUCING A SECONDARY TASK ON POSTURAL CONTROL IN OLDER ADULTS

Although research using probe reaction time tasks determined that there are age-related changes in attentional demands associated with postural control (Lajoie et al., 1996a; Teasdale et al., 1993), several studies have examined how postural control is altered after the introduction of a continuous secondary task (Maylor & Wing, 1996; Shumway-Cook et al., 1997; Brown et al., 1999). Maylor and Wing examined the effects of introducing different secondary tasks on postural control in adults (mean age 57 years) and older adults (mean age 77 years). Similar to the findings of Kerr et al. (1985), Maylor and Wing established that a visual/spatial task altered the interplay between postural control and cognitive performance. However, unlike the findings of Kerr and colleagues, older adults swayed more when performing the secondary task, indicating that task performance was prioritized over postural control.

To clarify the incongruent findings of Maylor and Wing (1996) and Kerr et al. (1985), Shumway-Cook and colleagues (1997) compared the effects of secondary task performance in older adults who had a previous history of falling and with those who had no fall experience. Subjects were asked to perform a secondary task while sensory information was altered during the postural tasks. Similar to Maylor and Wing (1996), performance on the cognitive task was not affected whereas postural sway increased with concurrent performance of the secondary task. The results of research from Maylor and Wing and Shumway-Cook et al. indicate that older adults may prioritize cognitive performance over postural control. One explanation for these findings is that more attention was focused on the cognitive task because the consequences of instability were not enough to warrant the allocation of resources to postural control (Shumway-Cook et al., 1997). Understanding the prioritization of postural control in older adults may help develop fall reduction programs that cater specifically to individuals who are at a risk of falling.

FALLING

Considering the musculoskeletal, sensory, and cognitive deteriorations that older adults face, it is understandable that the prevalence of falling in older adults is drastically higher than in younger adults. Indeed, falling has been identified as a prevalent health condition associated with functional decline (Tinetti & Williams, 1998). Recent studies have found that falling is a health problem that plagues over 30% of adults over the age of 65 (King et al., 1995). Falls can have serious implications in the elderly as over 40% of those who are injured in a fall are admitted to a hospital (Sattin et al., 1990). Hospitalization for recovery from a fall can result in a downward spiral of decreased cognitive function (Keefover, 1998), reduced physical and social activity, and loss of mobility and independence (Cutson, 1994). In fact, almost 50% of individuals who require hospital care after a fall are admitted to nursing homes (Sattin et al., 1990).

Recently a great deal of research has been devoted to determining fall risk in older adults. The primary factors that have been associated with fall risk are physical health, mobility, cognitive status (Vellas et al., 1998), environmental factors (Cummings & Nevitt, 1994; Cutson, 1994; Gabell, Simons, & Nayak, 1985), and psychosocial factors (Walker & Howland, 1991). Although, musculoskeletal, neuromuscular, and cognitive deteriorations have been discussed with respect to postural control, psychosocial factors such as anxiety, fear of falling, and low self-confidence may also affect postural control in older adults (Alexander, 1994; Silverton & Tideiksaar, 1989).

FEAR OF FALLING

Falls may not only be physically debilitating but may often also be damaging to the psyche as well. Many older adults report being less confident about their balance (Tinetti & Powell, 1993) and often report a fear of falling (Tinetti et al., 1998). Tinetti and colleagues (1994) examined measures of physical and social functioning in 1,103 community-living older adults over 70 years of age. These authors determined that 43% of the sample was afraid of falling and almost 20% of these individuals restricted their activity because of this fear. Many older adults avoid participation in physical activity because they possess irrational fears of becoming injured (O'Brien Cousins, 2000). After experiencing a fall, many older adults demonstrate a distinct and debilitating fear of falling again (Lach, Reed, Arfken, Miller, & Peck, 1989; Howland et al., 1993). However, even individuals who have not fallen may exhibit similar fears about injury from a loss of balance (Howland, Lachman, Peterson, Cote, & Jette, 1998; Tinetti et al., 1994). Thus, whether through real or vicarious experiences, older adults may have a constant preoccupying concern about losing their balance.

A fear of falling can affect postural control in three ways: 1) behavioural/motor responses often cause an individual to adopt a tense or stiff posture, 2) psychophysiological changes can increase the state of arousal that is experienced, 3) cognitive effects can cause people to have irrational thoughts about fear or potential threats in their environment (Yardley, 1998). Fear of falling may have a direct relationship with increased fall incidence and injury in older adults (Tinetti et al., 1998). Thus, because many older adults live with a persisting fear of losing their balance, understanding the effects of fear of falling on postural control may help reduce fall risk in this population.

Fear of Falling and Postural control

Maki, Holliday, and Topper, (1990, 1991) compared measures of postural control in older adults who reported a fear of falling with those who did not. Results indicated that postural sway increased significantly when the fear of falling group was asked to stand with their eyes closed. Many older adults who have a fear of falling express that they are often anxious about falling. To explore the effects of elevated anxiety produced by arousal, such as that incurred by a fear of falling, Maki and McIlroy (1996a) manipulated arousal in younger participants by asking them to perform a math test. Measures of galvanic skin response indicated that arousal increased in participants when they were performing the math task. Measures of postural control indicated that participants leaned forward and swayed more as arousal increased. However, because arousal was caused by the performance of a demanding task and not environmental factors, more pertinent results may be found by altering environmental constraints to create conditions that induce arousal from a fear of falling.

To induce arousal similar to that from fear of falling, recent studies have exploited the notion of postural threat by manipulating the environmental context while assessing postural control. Brown and Frank (1997) examined postural recovery from a perturbation in participants who were placed on an elevated platform in order to induce arousal from a postural threat. Results indicated that postural control was altered by the degree of postural threat; participants proactively adopted a posterior position of their COM (i.e. leaned backward) and maintained more conservative control over COM following perturbation in conditions of increased postural threat. Recent work by Carpenter and colleagues (1999) and Adkin et al. (2000) have confirmed the findings of Brown and Frank; younger participants appear to modulate postural control through a stiffening strategy in response to a threatening environment.

Adkin and colleagues (2000) used a forceplate to measure changes in COP in younger adults standing on a platform raised 40, 100, and 160cm from the ground. A linear decrease in sway was accompanied by an increase in frequency of sway, as conditions of postural threat became greater. Winter and colleagues (1998) determined that tighter control of COM is maintained by higher frequency in COP regulating forces. These authors hypothesize that a stiffer control of COM may be beneficial in responding more rapidly to postural perturbations than if an individual adopted a more 'relaxed' posture. Thus, when the consequences of instability are more critical, the CNS may actively regulate the COP as a self-preservation technique to recover more rapidly from a postural perturbation.

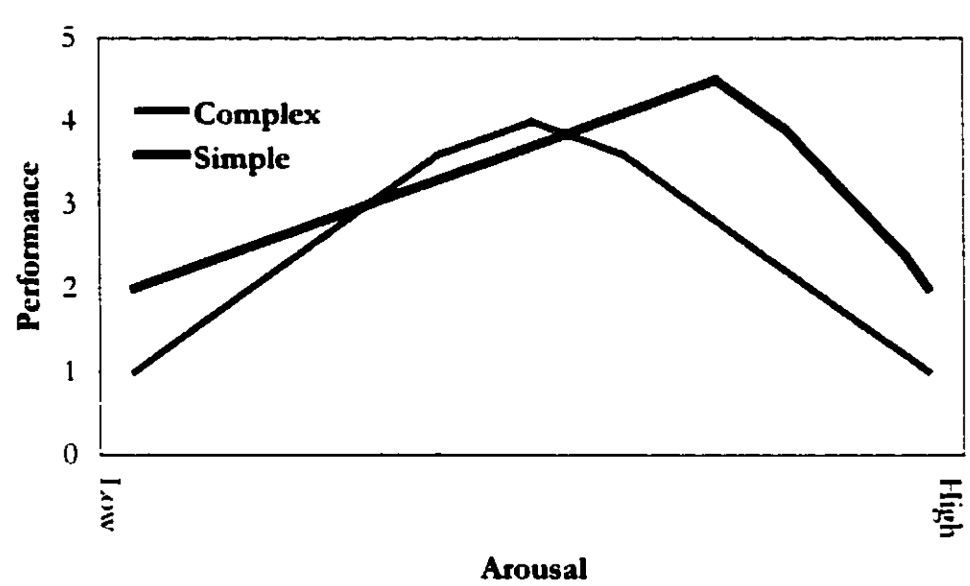

Figure 3 The inverted U function of arousal described by the Yerkes-Dodson Law (Yerkes-Dodson, 1908) for simple and complex tasks. Task performance improves with moderate levels of arousal but declines at low and high levels of arousal.

AROUSAL AND COGNITIVE PERFORMANCE

In conditions where older adults may be concerned about losing their balance, such as on an icy sidewalk or negotiating an escalator, everyday tasks such as talking with a friend or remembering directions may be compromised by changes in arousal. Research on arousal and attention has revealed that the level of arousal experienced by the participant can alter the performance of secondary tasks (Kahneman, 1973; Whyte, 1992; Broadhurst, 1959). Research has determined that moderate levels of arousal can improve cognitive performance of moderately difficult tasks. In addition, the Yerkes-Dodson law states that the quality of performance on a task is an inverted U function of arousal (see Figure 3). Thus, too much or too little arousal can reduce the performance of tasks. Therefore, according to this law, performance of a reaction time task in a dual-task paradigm would be best in conditions that provoked moderate levels of arousal (Kahneman, 1973). Similarly, arousal may have a beneficial effect on postural control because more attention may be directed toward the performance of the postural task than other tasks (Maki et al., 1991). However, too much arousal may have a negative effect on postural control because too much attention could be devoted to observing changes in the environment.

It is undeniable that older adults are more susceptible to falls than younger adults. However, many of the factors that increase fall risk may be preventable. For instance, occupational therapists can determine if an older adults home environment is unsafe and can teach older adults how to perform many daily activities without taking risks that could lead to a fall (Hornbrook et al., 1994). Exercise programs can be prescribed to strengthen musculature and develop skills to compensate for sensory deficits (Lord et al., 1994; Verfaillie, Nichols, Turkel, & Hovell, 1997; Shumway-Cook, Gruber, Baldwin, & Liao, 1997). Indeed, many studies have determined that older adults have concerns about their balance that can restrict participation in physical and social activities. Insufficient physical activity can reduce muscle strength and endurance as well as confidence about balance and neglecting social activities can lead to depression and dependence (O'Brien Cousins & Horne, 1998). Understanding the social-cognitive factors that are related to postural control and the incidence of falls may help shed new light on developing rehabilitation programs to improve the quality of life in older adults. Considering the overwhelming proportion of older adults who develop a fear of falling, it is now imperative that we address the effects of fear on postural control and associated cognitive mechanisms.

OBJECTIVES OF THE THESIS

The goal of this thesis was to examine the effects of postural threat on the role of cognition for postural control in younger and older adults. Two separate studies were completed to examine three different questions in this thesis: Study 1: Is the allocation of attention for postural control altered in young and older adults under conditions of postural threat? Study 2: Does secondary task performance effect postural control in younger and older adults under conditions of postural threat? Is the prioritization of postural control altered in younger and older adults when the potential consequences of postural control increase?

To examine these questions, performance under dual-task conditions on a discrete probe-reaction-time task and a continuous spatial memory task were monitored in conditions of postural threat. A discrete secondary task was used to determine the allocation of attention for postural control under conditions of postural threat. The continuous task was used to create competition for cognitive resources during concurrent performance of the primary postural task and the secondary cognitive task. In addition, measures of postural control were collected to determine if postural control was altered by conditions of postural threat and the performance of the secondary task.

Postural threat was manipulated by placing participants on an elevated platform and by positioning participants either in the middle or on the edge of the platform. The height manipulation served to increase the consequences of instability and the position manipulation prevented the opportunity to step to recover balance if necessary. Thus, a condition of low postural threat (LM) was created by positioning participants close to the ground and providing the possibility to step to recover their balance; by elevating participants off of the ground and preventing the ability to step forward, a condition of high postural threat (HE) was produced (see Figure 4, pg. 38).

In the first study, it was predicted that conditions of postural threat would alter the allocation of attention in younger and older adults. Specifically, it was hypothesized that greater cognitive resources would be allocated to postural control as postural threat increased. Based on age-related differences in the cognitive demands necessary for postural control (Lajoie, et al., 1996), it was expected that the shift in the allocation of attention would be greater in older adults than younger adults. The second study predicted that postural control would be disrupted by the introduction of the secondary task when postural threat was minimal but that balance would improve at the expense of secondary task performance as postural threat increased. Older adults were expected to be more affected by the performance of the secondary task and to place greater priority on postural control than secondary task performance compared to younger adults.

STUDY 1: THE ALLOCTION OF ATTENTION IS ALTERED IN CONDITIONS OF POSTURAL THREAT AMONG YOUNGER AND OLDER ADULTS: IMPLICATIONS FOR POSTURAL CONTROL

INTRODUCTION

There are a number of reasons for the increased rate of falls in the elderly. Research has shown that deteriorated postural control associated with increased age is a major contributing factor to instability in older adults (Woollacott, 1989). Even healthy older adults are often plagued by sensory and musculoskeletal deficits that reduce the ability to perceive and react to changes in the environment (Buchner et al., 1997; Black, Maki, & Fernie, 1993). Side-effects from medications, such as dizziness, blurred vision, and altered cognitive ability, can influence postural control and dramatically increase the risk of falling (Tideiksaar, 1997). In addition to these known risk factors, it is also true that many older adults fall because they do not pay enough attention to their surroundings. Furthermore, older adults may also be unable to direct enough attention to relevant cues for preventing falls. Therefore, older adults may be unable to perceive potential threats in the environment that can disrupt equilibrium, such as obstacles or icy surfaces (Chen et al., 1996). Thus, identifying how older adults allocate attention for postural control, particularly across varying environmental contexts, is important in understanding risk factors for falls in the elderly.

The allocation of attention for the performance of different tasks can depend on several factors. For example, the complexity of a task as well as the number of tasks that are performed simultaneously can alter how attention is distributed between tasks. In addition, the limited capacity model for attention dictates that there is a finite limit to the amount of attentional resources that can be directed to different tasks (Kahneman, 1973). Thus, according to this model, the performance of one or more tasks can diminish or fail if the demands of the tasks exceed the available attentional capacity.

It has already been established that postural control requires attention (Teasdale et al., 1993). Furthermore, research has indicated that postural tasks require more attention as the complexity of the postural task changes (Lajoie et al., 1993; Lajoie et al., 1996a). Finally, it is also known that older adults require greater cognitive resources for postural control than younger adults, particularly as task complexity increases (Teasdale et al., 1993; Lajoie et al., 1996a). Interestingly, older adults also exhibit age-related declines in cognitive capacity (Craik & Jennings, 1992). Thus, although older adults can still perform individual tasks adequately, multiple task performance may exceed the available capacity of attentional resources and compromise task performance. Furthermore, in addition to increased attentional requirements for tasks of postural control, age-related slowing of information processing (Salthouse et al., 1995) may also contribute to fall risk in older adults. For example, an older adult who unexpectedly "trips on a crack" in a sidewalk and falls, may not be prepared for this change in equilibrium and thus, may be unable to respond quickly enough to arrest the forward momentum of the body and recover balance. Indeed, age-related slowing of information processing has been indicated to significantly alter the effectiveness of postural recovery strategies from a perturbation (Stelmach et al., 1985). Thus, older adults may be at a greater risk of falling due to alterations in attention capacity and/or the processing speed to sufficiently perform a postural task.

In addition to age, task complexity, and the availability of cognitive resources, the level of physiological arousal is also known to affect the allocation of attention for performing different tasks simultaneously (Kahneman, 1973). For example, in a high-risk environmental context such as negotiating an icy stairway, even apparently simple tasks, such as maintaining a conversation with a friend while continuing to walk, may be altered because of changes in arousal (Li, Lindenberger, Freund, & Baltes, In Press). This shift in the allocation of attention may be mediated by increased arousal resulting from perceptions regarding the ability to preserve balance in a threatening environmental context or, likewise, from the potential consequences of an impending fall.

Interestingly, an individual's level of arousal alters their ability to perform a task. According to the Yerkes-Dodson law (Yerkes & Dodson, 1908), an inverted U function describing the level of arousal dictates that moderate levels of arousal improve task performance but arousal at either extreme is detrimental to task performance (Broadhurst, 1959). Thus, in situations of high (or low) arousal, the allocation of attention for performing a postural task may be altered. Because of the interplay between cognition and postural control, it is possible that balance may consequently be jeopardised because less attention can be allocated to maintaining equilibrium. It is possible that conditions of postural threat may require greater cognitive resources for maintaining postural control (Maki and McIlroy, 1996a). Thus, it is possible that fear of falling can be a precipitating factor to falls in the elderly because the heightened levels of arousal that accompany states of anxiety, such as a fear of falling, will alter the ability to effectively allocate attention to postural control (Maki et al., 1991).

To further explore the relationship between arousal and postural control, we exploited the notion of postural threat by manipulating the environmental context to increase the potential consequences of instability during quiet stance. The present study manipulated the environmental context to increase the potential consequences of falling and heighten arousal among younger and older adults. The specific purpose of this study was to investigate changes in the allocation of attention devoted to the control of upright standing when arousal is altered in younger and older adults. Following the principles of the dual-task paradigm, the allocation of attention was inferred from performance on a probe reaction time (PRT) task under 4 conditions of postural threat. It was hypothesized that the allocation of attention would be differentially altered in younger and older adults in response to levels of arousal from increased postural threat. Specifically, it was expected that greater cognitive demands would be necessary for postural control in older compared to younger adults in conditions of increased postural threat.

METHOD

PARTICIPANTS

Fifteen older (OA; 5 males, 10 females; age, 69.53 ± 5.78) and 15 younger adults (YA; 7 males and 8 females; age, 22.00, ± 2.17) participated in this study. All participants were free from neurological and orthopaedic conditions that may affect cognitive function and postural control. In addition, participants had no reported or overt aversions to heights. Older adults were required to clear a comprehensive neurological screening comprised of standard sensorimotor tests of function, an electronystagmogram to exclude potential vestibular pathologies, and a complete Mini-Mental State Evaluation to confirm cognitive status. A neurologist performed all neurological screenings.

Before testing commenced, all participants voluntarily provided informed consent according to guidelines of the Human Research Ethics Committee at the University of Lethbridge. In addition, participants were asked to complete a Falls History form that assessed their fear of falling (1 [not afraid] to 10 [very afraid]), fear of heights (y or n), and time since last fall (months) (see Appendix 1). Participants also completed the Gait Efficacy Scale (GES; McAuley, Mihalko, & Rosengren, 1997) and the Activities Specific Balance Confidence Scale (ABC; Powell & Myers, 1995) (see Appendix 2). These questionnaires were administered to assess participants' perceptions of their balance and their ability to perform daily activities. During testing, participants wore a tee-shirt or blouse, shorts, socked feet, and a safety harness over their clothes.

MANIPULATION OF POSTURAL THREAT

An industrial hydraulic lift table (1.2 X 1.8m; Pentalift, Guelph, ON) was used to alter the environmental context of the testing conditions and manipulate the level of postural threat imposed on the participant. Participants were tested under two vertical height positions: Low (0.17m) and High (1.4m) from ground level and at two positions on the lift table (Middle and Edge). Thus, four conditions of postural threat were included in this study: 1) Low-Mid (LM) – Middle of the platform at Low level, 2) Low-Edge (LE) – Edge of the platform at Low level, 3) High-Mid (HM) – Middle of the platform and elevated, and 4) High-Edge (HE) – Edge of the platform and elevated (see Figure 4). Middle and edge conditions were created to produce conditions of threat that did or did not permit an individual to step forward to recover their balance, should the need occur. The four different conditions modified the level of postural threat; Condition 1 (LM) was least threatening and Condition 4 (HE) provided the greatest postural threat.

PRESENTATION ORDER OF POSTURAL THREAT

To prevent carry-over effects of raising and lowering participants to different height conditions, a Latin-square design (Tabachnick & Fidell, 1996) was employed so that approximately the same number of participants could be randomly assigned to each of the 4 possible order combinations (i.e., 1 = LM, LE, HM, HE; 2 = LE, LM, HM, HE; 3 = HM, HE, LM, LE; 4 = HE, HM, LE, LM). Conditions 1 and 3 were each completed by 3 YA and 4 OA, condition 2 by 4 YA and OA, and condition 4 by 4 YA and 3 OA.

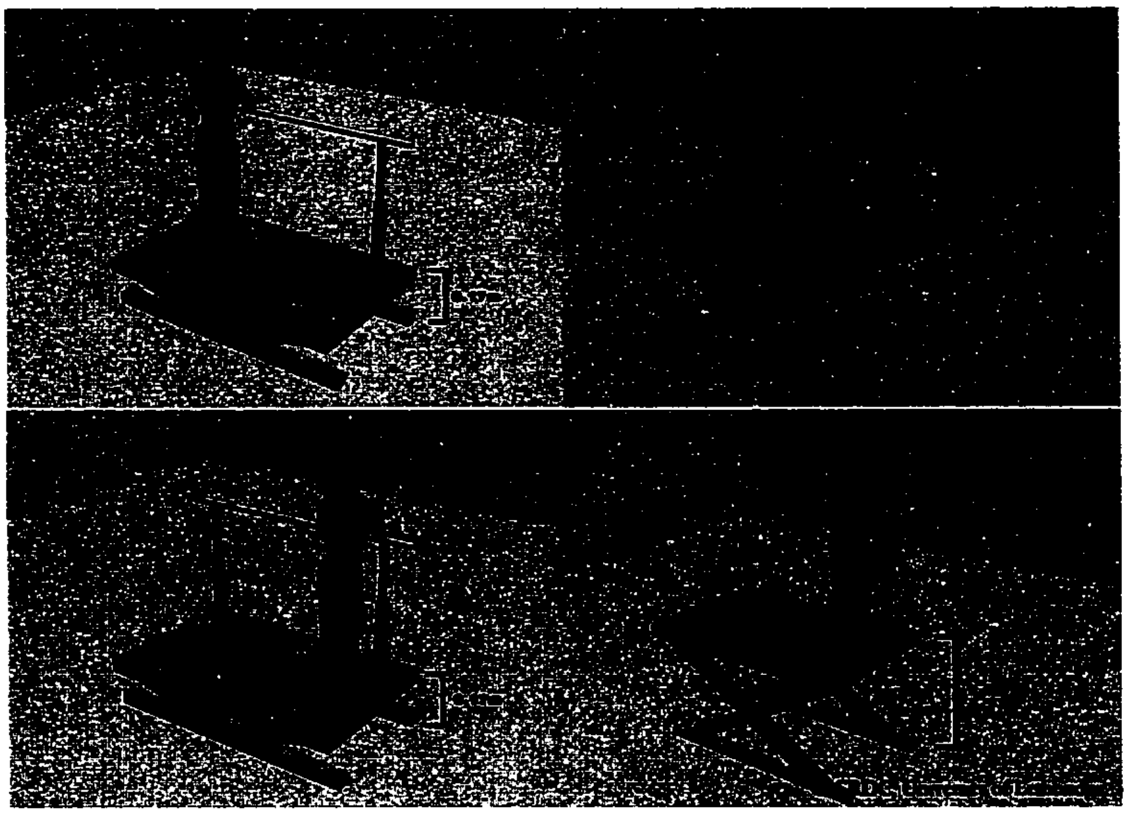

Figure 4 The experimental conditions for manipulating postural threat: a) Low-Mid (LM), b) Low-Edge (LE), c) High-Mid (HM), d) High-Edge (HE). Note: Participants were required to wear a safety harness in all conditions.

PROCEDURE

Participants were seated in a chair on the ground to receive instructions regarding the testing procedure and protocol. For the PRT task, participants were asked to verbally respond to the illumination of a red light located in the centre of a light display unit (University of Lethbridge Technical Services Department) as quickly as possible by saying the word "top" (Lajoie et al., 1993). The word "top" was used because it was unrelated to the task and was an easily articulated one-syllable word. The time interval between the warning signal and the light illumination was randomized across 9 delay intervals of 0.5s between 1.5 and 5.5 seconds. The participants were required to perform 4 practice trials to familiarize themselves with the task. Participants were also instructed how to perform Brooks' Spatial Letter Task (BST)* (Brooks, 1968) and were given a minimum of 6 practice trials to familiarize themselves with the task (data from this task will be presented in a subsequent study). After practice trials were completed, participants were asked to stand on one of two forceplates (one for middle and one for edge conditions; Type 4060-08, Bertec Corporation, Columbus, OH) with their feet at a comfortable width apart and so that their toes were flush with the leading edge of the forceplate. The position of the participant's feet was marked and measurements were recorded to ensure that foot placement remained constant in all trials. In each testing condition, a warning buzzer preceded illumination of the light and signalled that the trial was to begin.

Participants were required to complete 19 trials (excluding practice trials) in each of the four conditions of postural threat. Eight trials were performed while seated and 11 trials were completed while standing. The seated trials included 3 BST and 5 PRT tasks that were randomly presented in a blocked manner. After the sitting trials were completed a spotter removed the chair and participants were asked to stand on the forceplate and perform 5 PRT, 3 BST, and 3 Quiet Standing (QS) tasks. Standing trials were presented in a random blocked manner in each condition. Probe-reaction time tasks were presented 5 times to reduce within-subject variability and tasks were blocked in an effort to minimise testing time and confusion for the participants. Participants were required to stand with their arms crossed in front of their chest in all testing trials and a spotter remained near the participant at all times.

* BST data was not used in the present study and is presented in Study 2

INSTRUMENTATION

Forceplates were used to obtain ground reaction force and moment of force data necessary to calculate Centre of Pressure (COP) in each condition. A headset with a microphone was worn by the participant and used to collect audio data. Finger cuffs with silver/silver-chloride electrodes from a BioDerm Skin conductance Level Meter (UFI, Morro Bay, CA, USA) were attached to the middle phalanges of digits 3 and 4 to collect changes in Galvanic Skin Conductance (GSC). The light display unit was placed at eye level 2m in front of the participants and was adjusted for each condition to ensure consistency of the relative position between testing conditions. The light display unit was controlled by a delay and colour selector interface with inputs for the audio channel from the headset microphone. Audio data from the headset microphone were collected through an AW35 Pro Audio soundcard (sampling frequency = 22 KHz).

Analogue data were collected for 7 s during the PRT trials and 15 s during the QS trials. Collection times for audio data in the BST trials varied and were determined by the time required for the participant's performance of the task. Only data from 13 trials (5 PRT sitting, 5 PRT standing, and 3 QS) were analysed for each subject in this study.

MEASURES OF INTEREST

Results from the GES and ABC questionnaires were compiled to assess OA and YA's perceptions in their ability to perform daily activities in the home and within the community. In addition, results from the Falls History questionnaire were analysed to determine if OA and YA significantly differed on perceptions of fear of falling, fear of heights, and time since last fall.

Custom written algorithms were used to process all analogue data (Matlab, The MathWorks, Natick MA USA). Forceplate data were filtered using a 4^{th} order zero-lag Butterworth low-pass digital filter, at a cut-off frequency of 5 Hz. Co-ordinates for the anterior/posterior (A/P) (x) and medial/lateral (M/L) (y) positions of the COP, relative to the forceplate origin, were then calculated for the assessment of postural sway as follows:

COPx = My/Fz

COPy = Mx/Fz, where M = Moment of Force and F = Force

To normalize for differences in foot length and stance width, COP measures were expressed as a percentage of measured base-of-support for each subject (i.e., foot length for COPx and stance width for COPy). Mean COP position was determined in the A/P direction ((ΣCOPx)/samples) and total sway area was calculated (COPx range * COPy range). Data were cropped to the first second of collection to ensure that only data before the onset of the PRT warning signal were used.

Mean GSC data were processed and entered into a spreadsheet for statistical analysis. Reaction time latencies (latency = time from stimulus onset to onset of verbal response) were recorded for each individual by DOS-based program to within 1 ms and entered into a spreadsheet for further analysis.

DATA ANALYSIS

Due to technical difficulties, reaction time data were not collected for one younger male adult; data from 5 OA and 11 YA were used in the analysis for GSC. Results from participant information gathered from questionnaires were compiled and converted to percentages for each individual. Separate independent t-tests were used to determine differences in the mean total score of the combined GES and ABC scores, fear of falling, and time since last fall scores between YA and OA. A Chi Square test was used to determine statistical differences in the number of YA and OA that reported a fear of heights.

Mean values for GSC were entered into a 4-way (Age [YA vs. OA] X Height [Low vs. High] X Position [Middle vs. Edge] X Task [QS vs. PRT]) RM ANOVA. Probe reaction time scores were analysed in a 3-way (Age [YA vs. OA] X Height [Low vs. High] X Position [Middle vs. Edge]) Repeated Measures Analysis of Covariance (RM ANCOVA) using PRT values from the sitting LM condition as a covariate, to control for differences in conduction velocity and signal perception (Marsh et al., 2000; Tabachnick & Fidell, 1996).

Mean COPx position, and COP area were entered into two separate 4-way (Age [YA vs. OA] X Height [Low vs. High] X Position [Middle vs. Edge] X Task [QS vs. PRT]) RM ANOVA. Task was included as a variable to determine the effects of presentation of the PRT task on measures of COP. Post-hoc analyses were calculated on significant findings when necessary. Findings for all statistical tests were considered to be significant at $\alpha = 0.05$.

RESULTS

PARTICIPANT DATA

Results from independent t-tests revealed that scores on the GES and ABC questionnaires did not significantly differ between YA and OA adults (t (27) = 0.23, p > 0.05). Younger adults had a mean score of 94.18% compared to 93.74% in OA on the 26 questions asked on the questionnaires. This finding indicated that both groups perceived that they could adequately perform daily activities and function within the community. Participant history data revealed no significant differences between YA and OA in perceived fear of falling (t (27) = 0.36, p > 0.05) and fear of heights (X^2 (1) = 1.29, p > 0.05). However, when participants were asked to recall how long it had been since they last fell, YA were found to have fallen significantly more recently than OA (0.82 months vs. 31.60 months; t (27) = 2.14, p < 0.05). The discrepancy in time since last fall may be attributed to the fact that younger adults engage in more physical activities than most older adults (e.g. 50% of the falls in YA occurred while rollerblading).

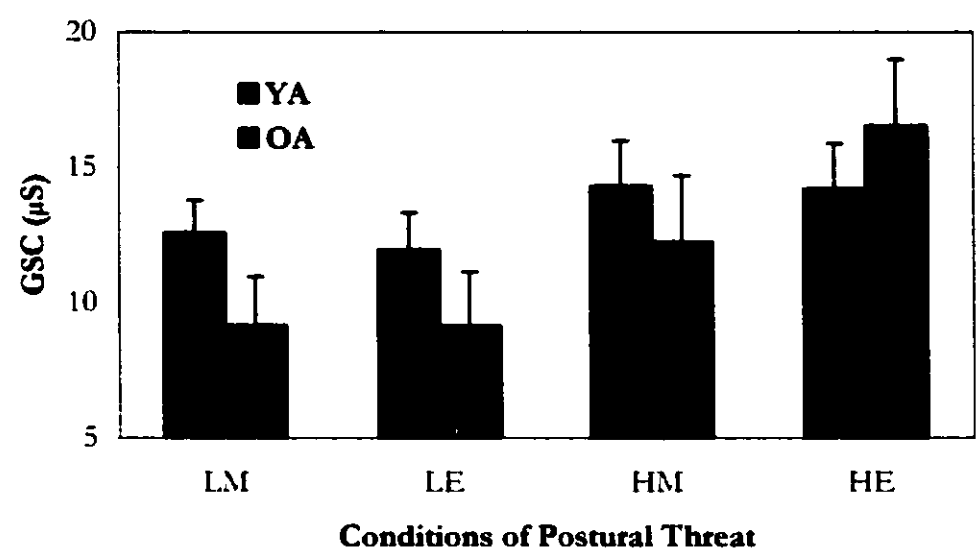

Figure 5 Galvanic Skin Conductance collapsed across task and group indicating that although arousal increased in both YA and OA with increased Height, OA were observed to have the greatest change in GSC in the HE condition. Data presented are means and standard errors (µS).

MEASURES OF AROUSAL

Results from the 4-way RM ANOVA revealed a main effect for Height (F (1,14) = 25.90, $p<0.05$) and a Height X Position interaction (F (1,14) = 5.50, $p<0.05$). Follow-up comparisons revealed that participants' GSC increased as Height increased and that participants experienced the highest GSC values when placed in the HE condition. GSC was not affected by the presentation of the PRT task (F (1,14) = 0.002, $p>0.05$; see Appendix 3 for statistical analyses). Although younger and older adults did not differ in arousal levels ($p>0.05$), a significant Task X Height X Age interaction (F (1,14) = 7.12,

$p<0.05$) indicated that an effect for Age emerged under PRT performance in elevated conditions. Older adults showed significantly greater GSC values compared to younger adults when anticipating the PRT task in the High conditions (see Figure 5).

REACTION TIME DATA

A significant main effect for Position (F (1,26) = 8.83, $p<0.05$) indicated that participants had faster PRT scores in Edge condition than in Middle conditions (see Appendix 4 for statistical analyses). Furthermore, a significant Height X Position interaction (F (1,26) = 7.48, $p<0.05$) revealed that participants had faster PRT values in the HE (375ms) condition compared to LM, LE, and HM (390ms, 395ms, 394ms). Separate 2X2 RM ANCOVA within each age group revealed that a significant main effect for Position (F (1,13) = 6.01, $p<0.05$) and a significant interaction between Height X Position (F (1,13) = 13.44, $p<0.05$) emerged among OA only. Data revealed that PRT scores in OA were faster in the Edge conditions compared to Middle conditions (Position) and compared to LM, LE, and HM conditions OA were fastest in the HE condition (see Figure 6).

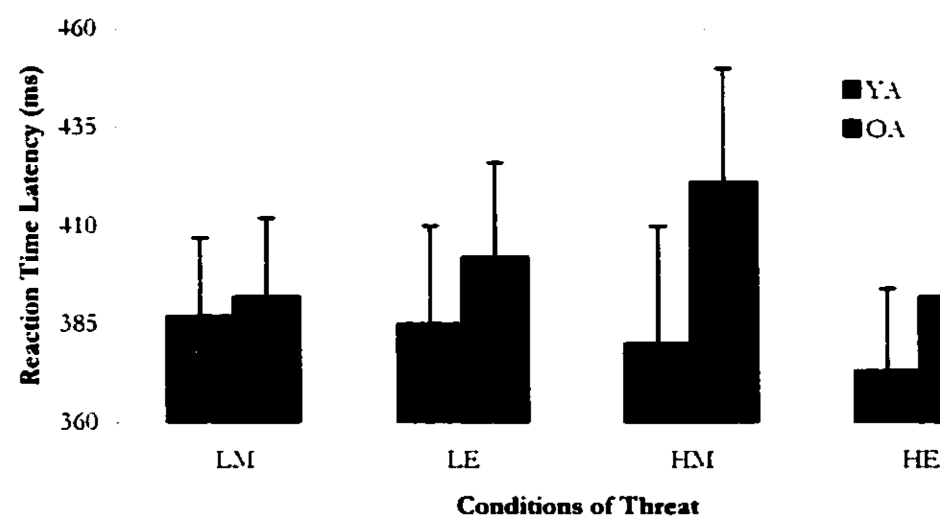

Figure 6 Probe reaction time latency values (ms) for younger and older adults in each conditions of postural threat indicating that both YA and OA had faster PRT latencies in the HE condition. Data presented are means and standard errors of raw data.

FORCEPLATE DATA

COPx Mean Position

Mean COPx position was not altered by the presentation of the PRT task (1,27) = 0.96, $p>0.05$). However, regardless of the task performed, all participants adjusted COP mean position and adopted a more posterior mean position in the High and Edge conditions compared to Low and Middle positions (Height X Position, F (1,27) = 33.10, $p<0.05$; Height, F (1,27) = 10.44, $p<0.05$; Position, F (1,27) = 24.67, $p<0.05$; see Appendix 5 for statistical analyses; see Figure 7). Furthermore, a significant between-subjects effect revealed that OA adopted a more posterior mean position than YA (F (1,27) = 4.58, $p<0.05$) across all conditions of testing.

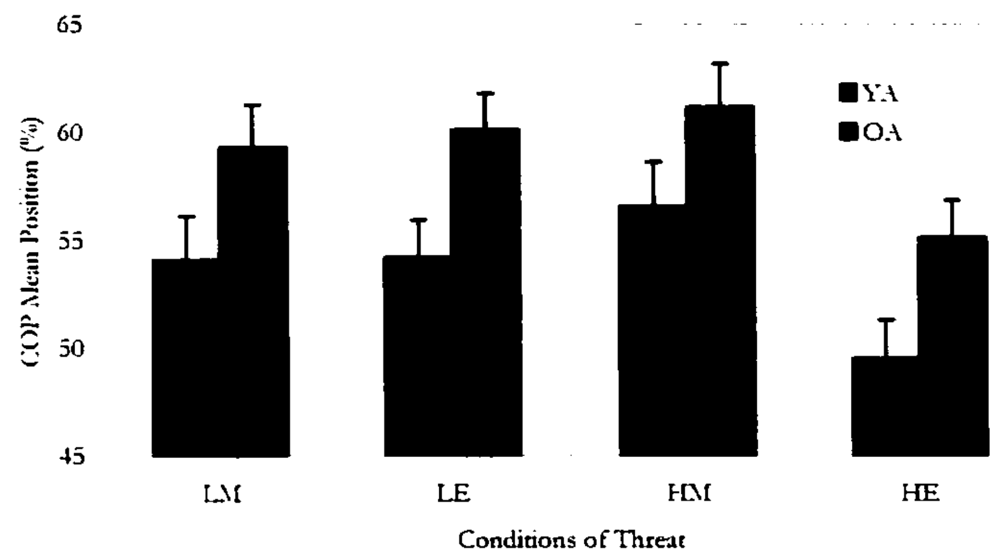

Figure 7 Data from Centre of Pressure mean position (COPx) in the anterior/posterior direction in YA and OA indicating that participants leaned backward in the HE condition. Data are mean and standard error for COPx position as a percentage of BOS referenced to forceplate centre.

COP Area

The presentation of the PRT task did not alter COP area (F (1,27) = 2.94, $p>0.05$; see Appendix 6 for results from statistical analyses). However, a main effect for Age revealed that OA had greater COP area compared to YA (F (1,27) = 7.59, $p<0.05$). A main effect for Position revealed that for all participants, COP area was significantly larger in Edge conditions compared to Middle conditions (F (1,27) = 4.61, $p<0.05$; see Figure 8), however, COP Area was not significantly altered with the manipulation of Height (F (1,27) = 0.035, $p>0.05$).

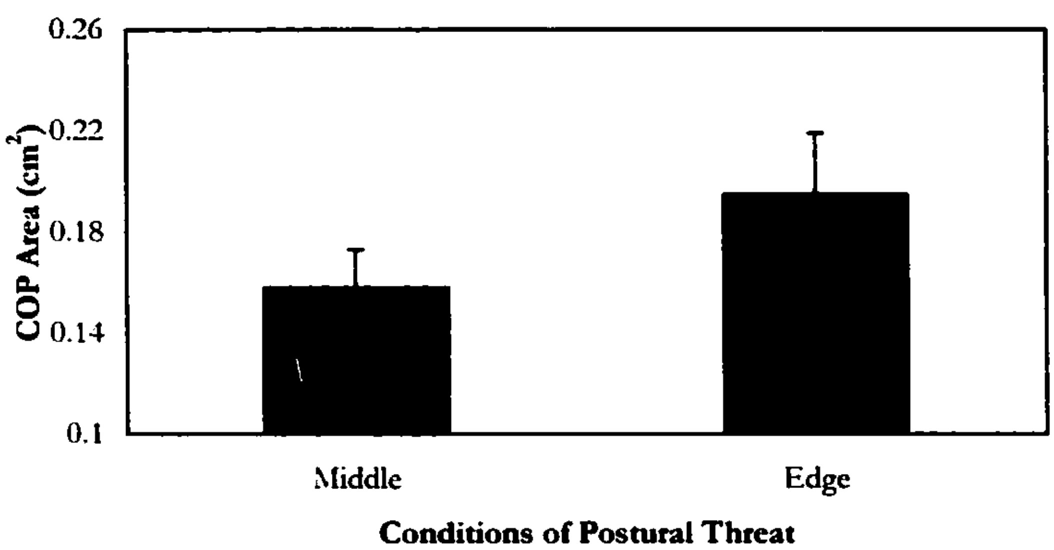

Figure 8 Results from measures of Centre of Pressure area revealing a reduced mean area in Edge conditions. Data are means and standard errors, collapsed by height, task, and age (cm^2).

DISCUSSION

The purpose of this study was to examine changes in the allocation of attention during the control of upright standing under conditions of postural threat. To achieve this goal we monitored changes in probe-reaction-time and postural control under conditions that altered the level of postural threat, increased the potential consequences of instability, and heightened physiological arousal. To determine whether different testing conditions altered anxiety, we assessed changes in physiological arousal. Results indicated that arousal increased across the testing conditions. Our results confirmed that regardless of age, the highest levels of arousal were produced in the HE condition and the lowest levels of arousal were found in the LM and LE conditions. Furthermore, our observations of participants' behaviours confirmed the results from our physiological measures with many participants stepping away from the edge of the platform or holding on to the handrail between testing trials in the HE condition. Finally, probe-reaction time data confirmed our hypothesis that conditions that increase postural threat and elevate arousal may alter the allocation of attention differently between younger and older adults. However, contrary to our hypothesis, results indicated that fewer cognitive resources may be allocated to postural control in conditions of increased postural threat, particularly in OA.

When data were examined within groups, it was found that PRT values for OA were fastest in the HE condition (see Figure 6; pg. 45). One possible interpretation of these results may be that the elevated levels of arousal induced by the HE condition altered PRT response performance. Indeed, OA, who were observed to have the greatest improvements in PRT, were also shown to have greatest change in arousal. Easterbrook's hypothesis (Easterbrook, 1959) suggests that individuals pay more attention to relevant cues during conditions of increased arousal. Therefore, it is possible that reaction times among OA were faster in the HE condition because elevated levels of arousal enhanced the ability to focus on cues pertinent to the PRT task. Indeed, the ability to attend to relevant cues during conditions of heightened arousal may be beneficial because an individual can respond faster to emergencies (Sapolsky, 1992). For example, Stelmach and Worringham (1985) have suggested that even minute reductions in response times to an unexpected balance disturbance can drastically affect the ability to recover postural control. Thus, arousal may be a beneficial response to threatening conditions by improving the response time to possible perturbations.

The observed improvement in PRT performance implies that greater attentional resources were directed to the performance of the PRT task. In this case it is also possible that attentional resources were directed away from postural control. Although reducing the amount of attention that is directed to postural control may potentially jeopardise postural stability (Teasdale et al., 1993), we believe that this shift in attention was permitted by compensatory postural changes that may serve to conserve the attentional requirements of the postural task. Our results indicated that although COP area increased in Edge conditions, the participants also adjusted the position of the COP further away from the edge, particularly in the HE condition (see Figures 7 & 8; pgs. 46 & 47). A posterior shift in mean COP position has been observed in several studies examining postural threat (Adkin et al., 2000; Carpenter et al., 1999; Brown & Frank, 1997). These authors unanimously hypothesized that a more posterior position of COP allowed for a greater margin of safety to recover from a perturbation because the mass of the body was moved further away from potential environmental threats. We propose that this postural adaptation may function to release cognitive resources from postural control and permit redirecting attention to other tasks. Interestingly, OA adopted a more posterior mean COP position than younger adults, regardless of conditions of postural threat. Perhaps older adults adopt a posterior leaning strategy to compensate for diminished postural stability or reduced confidence in balance, even in situations where there is no postural threat. Recent research from our laboratory has determined that under conditions of postural threat, OA also adjust their gait pattern to enable more cognitive resources to remain available for maintaining equilibrium on an elevated balance beam (Gage, Brown, Sleik, Polych, & McKenzie, Submitted). These results provide support for our hypothesis that conditions of postural threat alter the allocation of attentional demands for postural control in OA.

Although our findings indicate that arousal alters the allocation of attention without detrimental consequences to stability, it must be cautioned that too much arousal may jeopardize postural control (Maki et al., 1991). The individuals in the present study were healthy community-dwelling seniors. It is likely that the majority individuals who are debilitated by a fear of falling are frail elderly who may not be capable of generating appropriate postural adaptations in conditions that intensify arousal. Consequently, postural stability in these individuals may falter and a fall may occur. In addition, balance in OA may be disrupted in situations that distract attention from balance, such as when concurrently walking and talking, possibly leading to increased fall risk (Lundin-Olsson et al., 1997).

Studies that employ a demanding secondary cognitive task to loads the cognitive system with a cognitively demanding secondary task will help to determine the allocation of resources when a continuous task is performed and thus, can help assess shifts in the prioritization of postural control over secondary task performance. According to the capacity model for attention (Kahneman, 1973), there is a finite amount of cognitive resources available for performing concurrent tasks. If the capacity available for performing concurrent tasks is exceeded, performance on one or more tasks will deteriorate. The available capacity can depend on a variety of factors, including task difficulty and the number of tasks involved. Of particular relevance to this study however, it is also known that arousal can effect the allocation of cognitive resources required for performing different tasks (Kahneman, 1973). Older adults are known to have reduced processing speed (Salthouse et al., 1995), and cognitive capacities (Craik et al., 1982) than YA and therefore, age-related factors may also have a direct impact on secondary task performance. Therefore, future research should address how postural control in the elderly is affected when the cognitive system is loaded in conditions of environmental threat.

Our findings indicate that changes in environmental context that produce physiological of arousal will alter the allocation of attention during simple postural tasks. We propose that the allocation of attention is altered by factors that increase the focus of relevant cues and permit the redirection of attentional resources to facilitate performance of other tasks. Preserving attentional resources for responding to different situations, such as unexpected obstacles or icy surfaces, may be beneficial for recovering from an external perturbation by hastening responses that function to recover postural stability. Thus, our results indicate that heightened arousal may serve to reduce fall risk by directing attention to locate potential threats in the environment or to recovering from a loss of balance. However, greater levels of arousal, such as an intense fear of falling, may also have a detrimental effect on postural control by redirecting too much attention away from the postural task or by impeding postural adaptations that allow for changes in the allocation of attention. It is clear that more research needs to be conducted to elucidate how heightened arousal alters postural control.

STUDY 2: IS THE PRIORITIZATION OF POSTURAL CONTROL ALTERED IN CONDITIONS OF POSTURAL THREAT IN YOUNGER AND OLDER ADULTS?

INTRODUCTION

Effective postural control is necessary to permit the maintenance of equilibrium when moving and orienting within the environment. However, it is recognized that with age, postural control is significantly compromised (Maki et al., 1996b; Woollacott, 1989). Currently, falls in the elderly are extremely prevalent with approximately 30-40% of community dwelling adults over the age of 65 experiencing at least one fall each year (King et al., 1995; Vellas et al., 1998). The consequences of falls are often serious with over 40% of older adults who fall being admitted to hospitals and about 50% of those being discharged to nursing homes (Sattin et al., 1990). Furthermore, fall related injuries account for 66% of deaths due to accident in those over 75 years of age (Hindmarsh & Estes, 1989). Considering that the growth of the population over the age of 65 is predicted to double in the next 20 years (Statistics Canada, 2000), the need to identify the risks and consequences of falls and related sequelae is now imperative. Research efforts have identified several risk factors for falls in the elderly. An emerging factor that has received much research attention, is the role of cognitive processes in postural control (e.g., Brown et al, 1999; Lajoie et al., 1993; Shumway-Cook et al., 1997). Research exploring this component of postural control has determined that the performance of daily activities, such as walking while maintaining a conversation, can have a negative effect on maintaining balance, particularly in elderly populations (Brown & Woollacott, 1998; Lindenberger et al., 2000; Lundin-Olsson, 1997; Maylor & Wing, 1996).

We now know that maintaining postural control is not an automatic task; rather, it is a process that requires cognitive resources (Teasdale et al., 1993). Furthermore, greater cognitive resources are necessary as a postural task becomes more difficult, such as when walking or balancing on one foot (Lajoie et al., 1993). In addition, older adults require greater cognitive resources than younger adults when performing the same postural tasks (Lajoie et al., 1996b; Marsh & Geel, 2000). According to the model of limited capacity, a finite amount of attentional resources are available for performing multiple tasks (Kahneman, 1973). However, if the cognitive requirements necessary for performing two concurrent tasks exceed the available attentional resources, performance on one or both tasks can deteriorate. Therefore, if insufficient attentional resources are available to adequately perform another task while maintaining equilibrium, postural control may be compromised and a fall may result. Because postural control relies on cognitive resources, the effects of performing concurrent tasks on postural control may be particularly deleterious among older adults (Brown et al., 1998) or pathological populations who may have cognitive deficits (Haggard, Cockburn, Cock, Fordham, & Wade, 2000).

To demonstrate the interplay between postural recovery and the cognitive processes necessary for postural control, Stelmach, Zelaznik, and Lowe (1990) compared the effect of performing a cognitive task on the ability to recover postural stability from a self-induced perturbation between younger and older adults. Although no incidences of instability were recorded, it was revealed that older adults required a significantly longer time to recover their balance than younger adults under dual-task conditions. Interestingly, Stelmach and colleagues suggested that recovery times among participants in their study might have deteriorated under the challenge of dual-task performance because they may have perceived that there was minimal risk of falling during the testing conditions. Thus, it is possible that when the risk of falling is minimal, greater opportunity to devote attentional resources to secondary tasks, rather than to the maintenance of postural control, is greater.

Recent research has suggested that secondary task performance can be prioritised over postural control in conditions that do not threaten balance (Maylor and Wing, 1996; Shumway-Cook et al., 1997). Maylor and Wing examined the effects of introducing different types of cognitive tasks on postural control and demonstrated that tasks that interfered with visual-spatial components of cognitive processes were most detrimental to postural stability. In addition, it was also revealed that the introduction of a secondary task had greater effects on balance in older adults compared to younger adults. In a similar study, Shumway-Cook and colleagues examined postural control during concurrent performance of a sentence completion task and a judgment of line orientation task in younger adults and older adults with and without a history of falls. Contrary to predictions that postural control would be maintained at the expense of secondary task performance, it was revealed that regardless of fall history, postural stability was significantly reduced when performing the sentence completion task. Interestingly however, balance was most impaired by the secondary task among older adults who had a history of falls. These results imply that individuals with impaired postural control (e.g., older adults with a history of falls), are more likely to lose their balance when performing a concurrent secondary task than individuals with normal balance. Indeed, a study by Lundin-Olsson and colleagues (1997) determined that many older adults in nursing homes were unable to walk while maintaining a conversation. After a 6-month follow-up it was determined that those who could not walk and talk at the same time had an 83% greater chance of falling. These findings provide evidence that the inability to perform concurrent tasks may have a significant impact on fall risk in elderly populations.

Although the results of previous studies indicate that postural stability may be neglected to maintain secondary task performance, it is possible that the prioritization of postural control may depend on environmental factors that alter the level of postural threat, such as anxiety regarding walking ability on an icy sidewalk (Shumway-Cook et al., 1997). To explore how postural control may be modified under conditions of postural threat, several studies have monitored postural control under different environmental contexts. Brown and Frank (1997) examined postural recovery following a perturbation in young adults under an altered environmental context that increased the consequences of instability. Results indicated that participants made compensatory postural adjustments to reduce the possibility of falling in response to environmental conditions that increased the consequences of instability. In particular, participants proactively leaned backward prior to the perturbation and altered their postural recovery strategy to maintain a more conservative control over balance in conditions of increased postural threat. A more conservative control over balance was determined by reduced deviation of COM movement under the threatening conditions.

Recent work by Carpenter and colleagues (1999) and Adkin et al. (2000) have confirmed the findings of Brown and Frank (1997) younger participants appear to improve postural control when postural threat is elevated. However, although individuals appear to prioritize postural control under conditions of postural threat, it remains to be determined whether this apparent prioritization toward postural control is preserved during secondary cognitive task performance. Therefore, the purpose of this study was to examine the relationship between secondary cognitive task performance and postural control under environmental conditions that altered postural threat. Furthermore, because differences exist in cognitive capacity (Craik et al., 1982) and fall risk (Tideiksaar, 1997) between younger and older adults, a secondary purpose of this study was to investigate whether age-related differences existed in the propensity for a prioritization of postural control under conditions of postural threat.

Postural threat was manipulated by altering environmental constraints to create conditions that would increase the potential consequences of falling and heighten arousal in younger and older adults (Brown and Frank, 1997; Carpenter et al., 1999; Adkin et al., 2000). Brooks' spatial memory task (Brooks, 1968) was introduced while the participants performed quiet standing in 4 conditions of increasing postural threat. It was predicted that postural control would be prioritized at the expense of secondary task performance as postural threat increased. However, it was also hypothesized that the tendency toward prioritization of postural control would be most apparent in older adults compared to younger adults in the same conditions.

METHODS

PARTICIPANTS

Fifteen older (OA; 5 males, 10 females; age, 69.53 ±5.78) and 15 younger adults (YA; 7 males and 8 females; age, 22.00 ±2.17) participated in this study. All participants were free from neurological and orthopaedic conditions that may affect cognitive function and postural control. In addition, participants had no reported or overt aversions to heights. Older adults were required to clear a comprehensive neurological screening comprised of standard sensorimotor tests of function, an electronystagmogram to exclude potential vestibular pathologies, and a complete Mini-Mental State Evaluation to confirm cognitive status. A neurologist performed all neurological screenings.

Before testing commenced, all participants voluntarily provided informed consent according to guidelines of the Human Research Ethics Committee of the University of Lethbridge. In addition, participants were asked to complete a Falls History form that assessed fear of falling (scale 1 [not afraid] to 10 [very afraid]), fear of heights (y or n), and time since last fall (months). Participants also completed both the Gait Efficacy Scale (GES; McAuley et al., 1997) and the Activities Specific Balance Confidence Scale (ABC; Powell et al., 1995). These questionnaires were designed to assess participants' perceptions of their balance and their ability to perform daily activities. During testing, participants wore a tee-shirt or blouse, shorts, socked feet, and a safety harness over their clothes.

MANIPULATION OF POSTURAL THREAT

An industrial hydraulic lift table (1.2 X 1.8m; Pentalift, Guelph, ON) was used to alter the environmental context of the testing conditions. Participants were tested under two vertical height positions; Low (0.17m) and High (1.4m) from ground level and two position conditions on the lift table (Middle and Edge). Thus, 4 conditions of postural threat were included in this study: 1) Low-Mid (LM) – Middle of the platform at ground level 2) Low-Edge (LE) – Edge of the platform at ground level 3) High-Mid (HM) – Middle of the platform and elevated 4) High-Edge (HE) – Edge of the platform and elevated (See Figure 4; pg. 38). Middle and edge conditions were created to produce conditions of threat that did or did not permit an individual to step forward to recover their balance. The four different conditions modified the level of postural threat and consequently, Condition 1 (LM) was least threatening and Condition 4 (HE) provided the most postural threat.

PRESENTATION ORDER OF POSTURAL THREAT

A Latin-square design (Tabachnick & Fidell, 1996) was employed so that approximately the same number of participants could be randomly assigned to each of the 4 possible order combinations (i.e., 1 = LM, LE, HM, HE; 2 = LE, LM, HM, HE; 3 = HM, HE, LM, LE; 4 = HE, HM, LE, LM). This method was used to prevent carry-over effects from raising and lowering participants to different height conditions. Conditions 1 and 3 were each completed by 3 YA and OA, condition 2 by 4 YA and 3 OA, and condition 4 by 4 YA and OA.

PROCEDURE

Participants were seated in a chair on the ground to receive instructions regarding the testing procedure and protocol for Brooks Spatial Letter Task (BST) (Brooks, 1968).

Participants were presented with 16 different 8 x 11" cards showing a large simple block letter (i.e., G, H, J, M, S, W, Y, E) approximately 10" tall. Two cards were made for each letter so that each card had an asterix printed on either the bottom-left or top-right corner of the letter to indicate the "starting point" (see * Figure 9). Participants were allowed to view the letter until they felt they had a clear mental image of it. The letter was then taken away and participants were asked to start classifying the letter, according to the set criteria, out loud from one of two predetermined starting points. The BST task required participants to visualize the block letter and to trace the perimeter of the letter in their mind. Each corner of the letter was to be classified with either a "yes" or a "no" according to set criterion. The criteria were either "top/bottom" indicating that any corners on the extreme top or bottom of the letter received a "yes" answer, or "left/right" indicating that the corners on the extreme left or right edges of the letter receive a "yes" answer (see Figure 9). Classification criteria and the presentation of letters were randomized so participants were unable to predict or memorize the answers for the task. A minimum of 6 practice trials was given to familiarize participants with the task but testing did not proceed until the participants were comfortable and proficient at performing the task.

Participants were also trained to perform a probe-reaction time task (PRT)*. Practice trials were allowed for this task as well. After practice trials were completed for both tasks, participants were asked to stand on the forceplates with their feet at a comfortable width apart and so that their toes were flush with the leading edge of the forceplate. The position of the participant's feet was marked and measurements were recorded to ensure that foot placement remained constant in all trials. Participants were required to complete 19 trials (not including practice trials) in each of the four conditions of postural threat. Eight trials were performed while seated and 11 trials were completed while standing. The seated trials included 3 BST and 5 PRT tasks that were randomly

* PRT data was not used in the present study and is reported in Study 1.

presented in a blocked manner. After the sitting trials were completed, a spotter removed the chair and participants were asked to stand on the forceplate to perform 5 PRT, 3 BST, and 3 Quiet Standing (QS) tasks. Standing trials were presented in a random blocked manner in each condition. Participants were required to stand with their arms crossed in front of their chest in all testing trials and a spotter remained near the participant at all times.

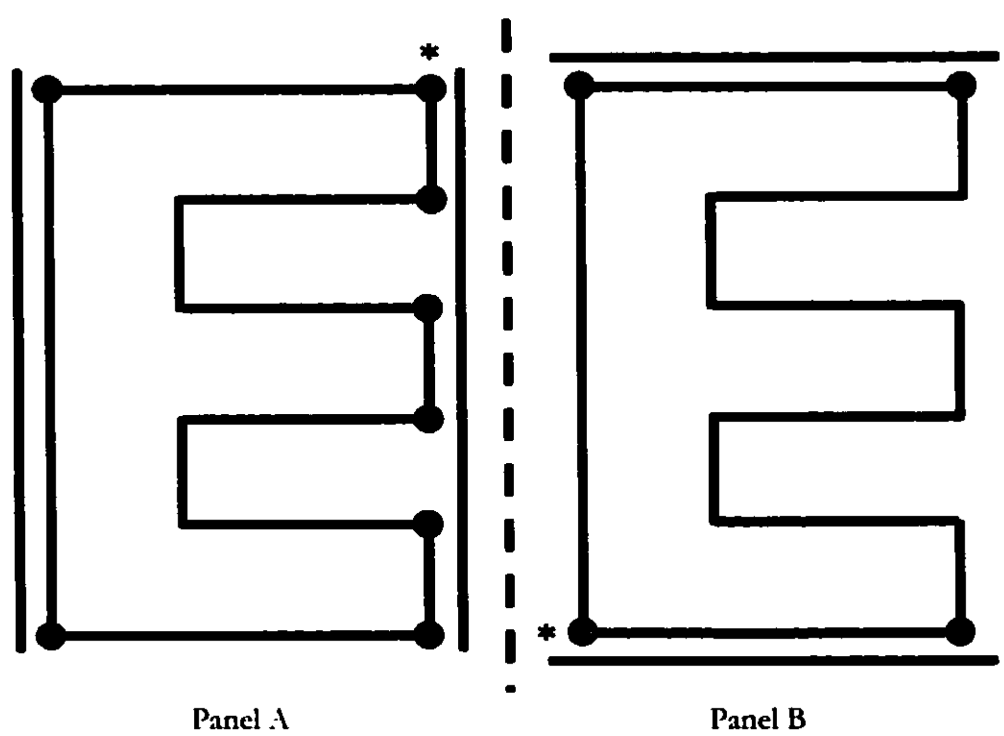

Figure 9 A sample 12 point block letter used for Brooks' Spatial Letter Task (BST). Lines outside the letter indicate the conditions. Participants started at either the top/right or the bottom/left of the diagram indicated by the *. Panel A presents the extreme left/right condition, in which the correct series of responses, starting from the top/right corner would be: Yes, Yes, No, No, Yes, Yes, No, No, Yes, Yes, Yes, Yes, Yes. Panel B presents the extreme top/bottom condition, in which the correct series of responses, starting from the bottom left corner would be: Yes, Yes, Yes, No, No, No, No, No, No, No, No, Yes.

INSTRUMENTATION

Forceplates were used to obtain ground reaction force and moment of force data necessary to calculate Centre of Pressure (COP) in each condition. A headset with a microphone was worn by the participant and used to collect audio data for the BST and PRT tasks. Audio data from the headset microphone were collected on a separate collection computer through an AW35 Pro Audio soundcard (sampling frequency = 22 KHz). Finger cuffs with silver/silver-chloride electrodes from a BioDerm Skin conductance Level Meter (UFI, Morro Bay, CA, USA) were attached to the middle phalanges of digits 3 and 4 to collect Galvanic Skin Conductance (GSC) data.

Analogue data were collected for 7 s during the PRT trials and for 15 s during the QS trials. Collection times for audio data in the BST trials varied depending upon the time required for the participant's performance of the task (M = 14.19 ± 2.21). Only data from 9 trials (3 BST sitting, 3 BST standing, and 3 QS) were analysed for each subject in this study.

MEASURES OF INTEREST

Results from the GES and ABC questionnaires were compiled to assess perceptions regarding the ability to perform daily activities in the home and within the community for YA and OA. In addition, results from the falls history questionnaire were analysed to determine if OA and YA significantly differed on perceptions of fear of falling, fear of heights, and time since last fall.

Custom written algorithms were used to process all analogue data (Matlab, The MathWorks, Natick MA USA). Forceplate data were filtered using a 4^{th} order zero-lag Butterworth low-pass digital filter, at a cut-off frequency of 5 Hz. Co-ordinates for the anterior/posterior (x) and medial/lateral (y) positions of the Centre of Pressure (COP), relative to the forceplate origin, were then calculated for the assessment of postural sway as follows:

$$COPx = My/Fz$$

$$COPy = Mx/Fz, \quad \text{where } M = \text{moment of force and } F = \text{Force}$$

To normalize for differences in foot length and stance width, COP measures were expressed as a percentage of measured base-of-support for each subject (i.e., foot length for COPx and stance width for COPy). Centre of Pressure area was calculated (COPx range * COPy range) for each condition. Data were cropped to the first 3.5 seconds of the collection to ensure that only data during the shortest BST response time (4 s) were used. Mean GSC data were processed and entered into a spreadsheet for statistical analysis. Verbal responses from the BST task were monitored and errors were recorded.

DATA ANALYSIS

Data from BST trials were not collected for two older adults because they were unable to perform the task. In addition, due to technical limitations, data from 5 OA and 11 YA were used in the analysis for GSC. Results from participant information gathered from questionnaires were compiled and converted to percentages for each individual. Separate independent t-tests were used to determine differences in the mean total score of the combined GES and ABC scores, fear of falling, and time since last fall scores between YA and OA. A Chi Square test was used to determine statistical differences in the number of YA and OA that reported a fear of heights.

The means values for GSC were entered into a 4-way (Age [YA vs. OA] X Height [Low vs. High] X Position [Middle vs. Edge] X Task [QS vs. RT]) RM ANOVA. Mean COP area data were entered into a 4-way (Age [YA vs. OA] X Height [Low vs. High] X Position [Middle vs. Edge] X Task [QS vs. BST]) RM ANOVA. Task was included as a variable to determine the effects of presentation of the BST task on measures of COP. Mean durations from the BST were analysed in a 3-way (Age [YA vs. OA] X Height [Low vs. High] X Position [Middle vs. Edge]) Repeated Measures Analysis of Covariance (RM ANCOVA) using BST values from the sitting LM condition as a covariate, to control for differences in response times and memory performance; (Marsh et al., 2000; Tabachnick & Fidell, 1996). When necessary, appropriate post-hoc analyses were calculated.

A Prioritization Index was calculated to quantify changes in the relationship between postural control and secondary task performance. The Prioritization Index was obtained by comparing the percent change in postural performance and secondary task performance across the testing conditions. Change in postural performance was assessed using COP area by calculating the percent change from the LM condition while performing the BST in the LE, HM, and HE conditions (e.g., [LM–LE] / LM *100). Change in secondary task performance was calculated by the percent change in the LE, HM, and HE conditions from the duration of the LM condition (e.g., [LM – LE] / LM *100). For the Prioritization Index, a score was assigned for each participant according to the following criteria: 1) Posture prioritized = reduced area and longer duration on BST, 2) No prioritization = all other possible combinations. The number of participants who revealed postural prioritization versus the number of participants who did not prioritize posture first was then assessed by Chi-Square analysis in order to determine significant differences in frequencies. Findings for all statistical tests were considered to be significant at $\alpha = 0.05$.

RESULTS

PARTICIPANT DATA

Results from independent t-tests revealed that scores on the GES and ABC questionnaires did not significantly differ in YA and OA adults (t (26) = -0.22, p > 0.05). Younger adults had a mean score of 93.82% compared to 94.26% in OA on the 26 questions asked on the questionnaire. This finding indicated that both groups perceived that they could adequately perform daily activities and function well within the community. Participant history data revealed no significant differences between YA and OA in perceived fear of falling (t (26) = 0.39, p > 0.05) and fear of heights (X^2 (1) = 1.29, p > 0.05). However, when participants were asked to recall how long it has been since they last fell, YA were found to have fallen significantly more recently than OA (0.77 months vs. 36.46 months; t (26) = -2.46, p < 0.05). The discrepancy in time since last fall may be attributed to the fact that YA engage in more dangerous activities than most older adults (e.g., 50% of the falls in YA occurred while rollerblading).

MEASURES OF AROUSAL

Results from the 4-way RM ANOVA revealed a significant Task x Height x Position x Age interaction indicating that when performing the BST task, OA showed the highest levels of arousal in the HE condition (18.19 μS) compared to the LM condition (9.88 μS; F (1,4) = 6.96, p<0.05; see Figure 10). An interaction between Height x Position x Age (F (1,14) = 6.19, p<0.05) indicated that OA were more affected in the HE condition (1,4) = 4.573, p<0.05) compared to YA (1,10) = 0.011, p>0.05). Results also revealed a significant Height x Position interaction (F (1,14) = 7.66, p<0.05), and indicated that overall, participants revealed the highest levels of arousal in the HE condition (16.22 μS in HE vs. 11.01 μS in LM). A significant main effect for Task (F (1,14) = 6.19, p<0.05) indicated that the performance of the BST task significantly increased arousal. Overall means revealed that arousal changed from 12.50 μS during quiet stance to 13.39 μS while performing the BST. Significant main effects also emerged for Height (F (1,14) = 23.67, $p<0.05$) and Position (F (1,14) = 8.20, $p<0.05$) and revealed that arousal increased from the Low to High positions (11.15 S for Low vs. 14.73 μS for High) and the Middle to Edge positions (12.13 μS for Low vs. 13.75 μS for High). No other interactions were found to be significant and overall GSC values were not found to differ significantly between age groups ($p>0.05$).

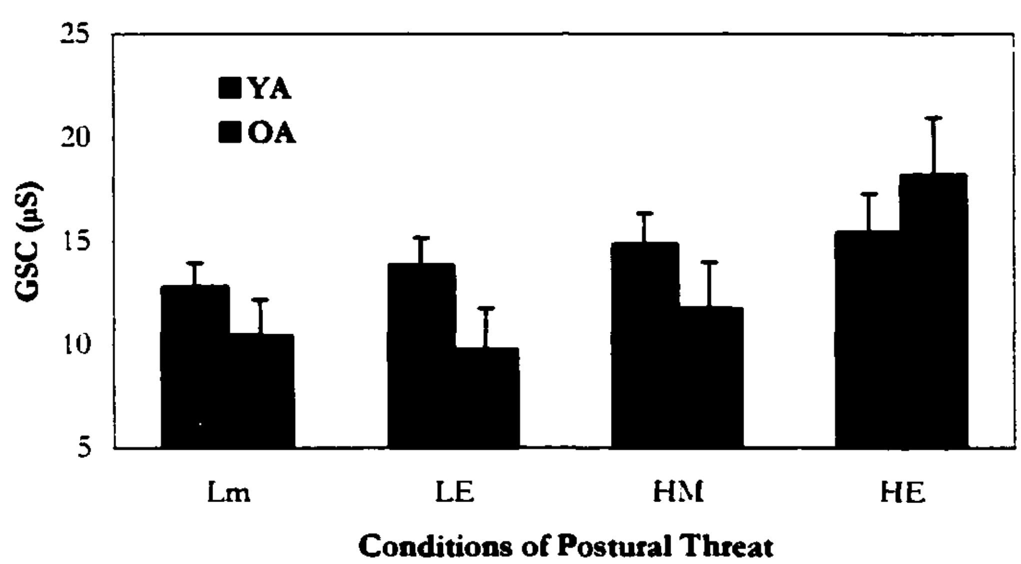

Figure 10 Mean level of arousal indicated by GSC in each condition of postural threat in YA and OA. Notice that GSC increased in YA and OA in the HE conditions but that OA had a significantly ($p < 0.05$) the greatest change in arousal in the HE condition. Values represent means and standard errors of data (μS).

A significant Height x Position interaction (F (1,25) = 5.06, $p<0.05$) indicated that regardless of age, BST performance in the height conditions was dependent on position (LM = 14.034s vs. HE = 14.345s; see Figure 11). Interactions were also found between Age x Height (F (1,25) = 7.65, $p<0.05$) and between Age x Position (F (1,25) = 13.64, $p<0.05$). Follow-up analyses revealed that as height increased from Low to High, YA performed the BST task significantly faster (F (1,13) = 12.77, $p<0.05$; 10.58s Low vs. 10.20s High) whereas OA performance on the BST task slowed with increased height (F (1,11) = 2.51, $p>0.05$; 17.85s Low vs. 18.71s High). A similar finding was noted in follow-up tests for Age x Position, and revealed that task performance significantly improved in YA from the Middle to the Edge conditions (F (1,13) = 9.69, $p<0.05$; 10.72s in Middle vs. 10.06s in Edge) whereas OA performance was significantly slowed by the change in position (F (1,11) = 4.88, $p<0.05$; 17.98s Middle vs. 18.58s Edge). Results from the 3-way RM ANCOVA on the mean duration to complete the BST task revealed that the Age x Height x Position interaction was not significant (F (1,25) = 0.49, $p>0.05$). Separate 2-way RM ANCOVA within OA and YA revealed that performance of the BST task was affected by Height and Position among OA only (F (1,11) = 11.396, $p<0.05$; 17.63s in LM vs. 19.08s in HE; see Figure 11).

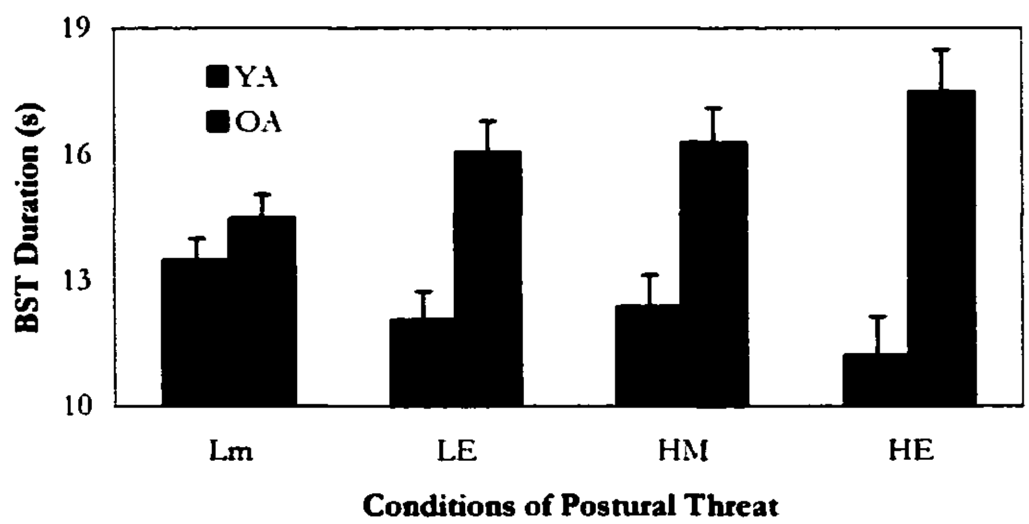

Figure 11 Mean duration to complete the BST task in each condition of postural threat in YA and OA. As postural threat increases, YA peform the BST task faster, whereas performance in OA is slowed. Data presented are means and standard error values (s).

A significant main effect was found for Height (F (1,25) = 9.73, $p<0.05$) and indicated that BST task performance was reduced in High conditions. In addition, a main effect for position (F (1,25) = 14.315, $p<0.05$) revealed that performance of the BST task slowed when participants were asked to stand at the edge of the platform. Finally, a significant between-groups main effect indicated that older adults were slower in performing the BST task than YA (F (1,25) = 15.84, $p<0.05$), regardless of condition of postural threat.

FORCEPLATE DATA

A significant Task x Height x Age interaction (F (1,26) = 4.49, $p<0.05$) indicated that OA significantly reduced COP area when performing the BST task in the High conditions compared to BST performance in low conditions (OA Low = 1.95 cm^2 and

High = 0.834 cm^2 vs. YA Low = 0.505 cm^2 and High = 0.450 cm^2; see Figure 12). In addition, a Height x Age interaction revealed that differences in COP area in response to Height were affected by Age, (F (1,26) = 11.73, $p<0.05$; OA Low = 0.802 cm^2 vs. OA High = 1.450 cm^2 and YA Low = 0.459 cm^2 vs. YA High = 0.416 cm^2).

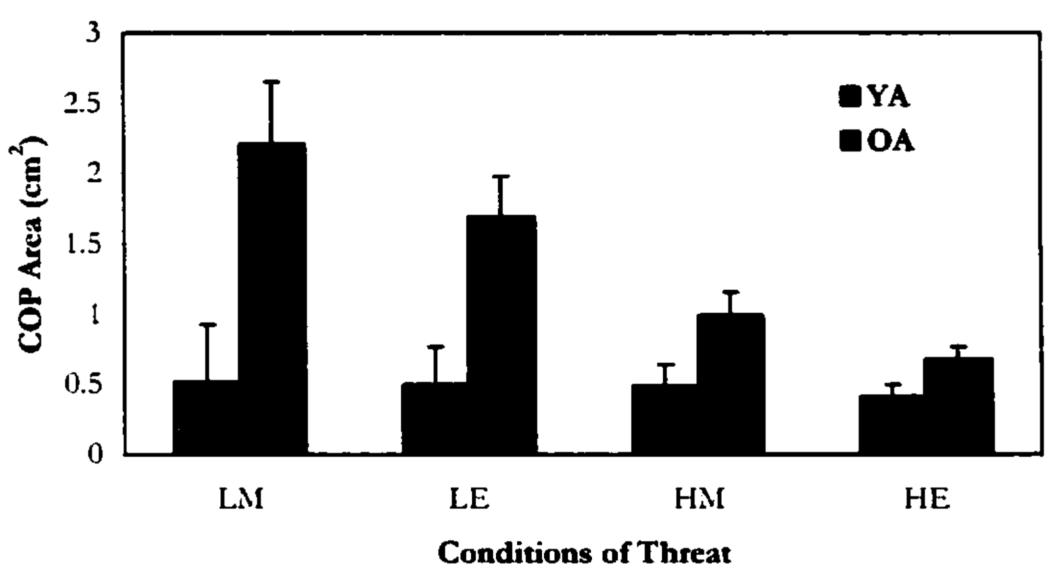

Figure 12 Mean COP Area in YA and OA while performing the BST task in the 4 conditions of postural threat. OA postural stability improves as postural threat increases. Data presented are mean and standard error values (cm^2).

As indicated by a significant Task x Height interaction, participants showed reduced COP area in the High conditions compared to the Low conditions when performing the BST task (F (1,26) = 4.49, $p<0.05$; QS Low = 0.68 cm^2 and QS High = 0.58 cm^2 vs. BST Low = 1.23 cm^2 and BST High = 0.64 cm^2). A significant main effect for Height revealed that regardless of Age, Task, or Position, participants showed reduced COP area in High (0.61 cm^2) compared to Low conditions (0.96 cm^2). No significant main effects were reported for position although mean values indicated that

COP area was reduced in Edge compared to Middle positions (Middle = 0.81 cm^2 vs. Edge = 0.75 cm^2).

EFFECTS OF SECONDARY TASK ON POSTURAL CONTROL

The main effect for Task was non-significant, although COP area increased by 50% when the secondary task was introduced (QS = 0.63 cm^2 vs. BST = 0.94 cm^2). Follow up tests for the Task x Height x Age interaction in COP area did not reveal any significant task interactions ($p > 0.05$) with either age group. However, measures did indicate that postural control was reduced in both age groups when performing the BST task (See Table 1). For instance, in the LM condition OA revealed a 133% increase in COP area measures (QS LM = 0.947 cm^2 vs. BST LM = 2.12 cm^2) and YA showed a 79% increase in COP area (QS LM = 0.287 cm^2 vs. BST LM = 0.513 cm^2) when performing the BST task under secondary task performance demands.

Table 1 Postural stability as indicated by COP area in YA and OA in each of the 4 conditions of postural threat during quiet stance (QS) and when performing Brooks' Spatial Task (BST). COP area in OA more than doubles from QS to BST in the LM condition. Data presented are means and standard error values (cm^2).

Group	YA		OA	
Task	QS	BST	QS	BST
LM	0.287 ± 0.16	0.513 ± 0.41	0.947 ± 0.17	2.210 ± 0.44
LE	0.540 ± 0.23	0.498 ± 0.27	0.955 ± 0.25	1.689 ± 0.29
HM	0.355 ± 0.09	0.488 ± 0.15	0.989 ± 0.10	0.989 ± 0.17
HE	0.407 ± 0.14	0.412 ± 0.08	0.822 ± 0.16	0.679 ± 0.09

The Prioritization Index revealed that more OA prioritized postural control than YA when in the HE condition. The percentage of YA and OA who prioritized postural control did not dramatically change in the LE (30.77% of OA vs. 40.00% of YA), and HM (23.08% of OA vs. 20.00 % of YA) conditions. However, more OA were found to prioritize postural control in the HE condition compared to YA (53.84% of OA vs. 20.00% of YA; see Figure 13). Frequency scores of OA and YA who prioritized postural control achieved near significance in the HE (X^2 (1) = 3.47, p=0.063) whereas frequencies in the LE and HM conditions did not approach the 0.05 α level.

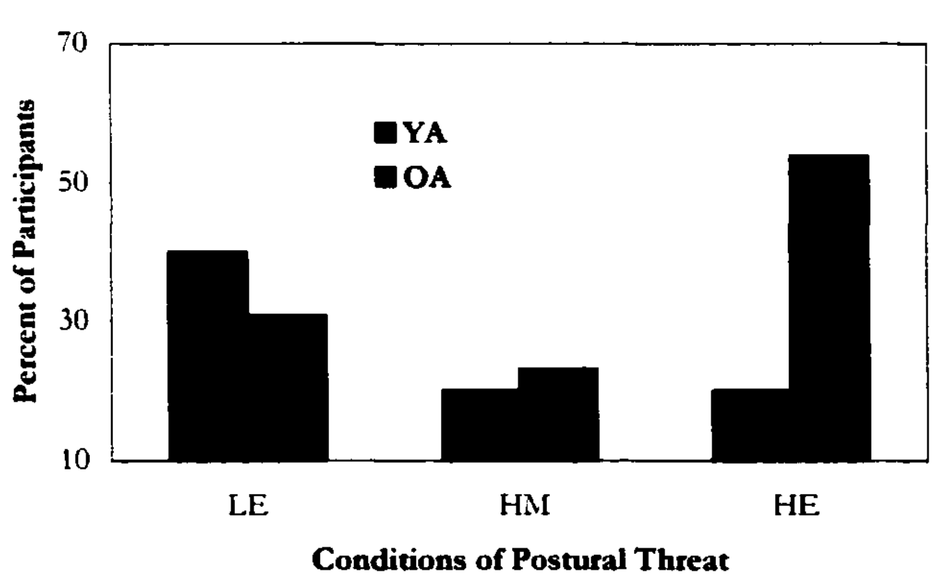

Figure 13 The percentage of YA and OA who prioritized postural control over secondary task performance according to the Prioritization Index. Prioritization was determined if postural control improved (reduced COP area) and secondary task perfomance was reduced (longer BST duration).

DISCUSSION

The purpose of this study was to examine the relationship between performance of a postural task and the concurrent performance of a secondary task in YA and OA in conditions of increasing postural threat. Younger and older participants were asked to concurrently perform Brooks' spatial memory task (Brooks, 1968) while maintaining static equilibrium under 4 conditions of increasing postural threat. Changes in BST task performance and postural control were monitored in each trial and used for the calculation of the Prioritization Index. Results revealed that the relationship between postural control and BST task performance was altered by postural threat. In particular, as postural threat increased, postural stability improved and performance on the secondary task deteriorated. This finding, however, was exclusive to OA. Results from YA indicated that postural stability and secondary task performance improved in conditions of increased postural threat. These findings confirm our hypothesis that in OA, postural control is maintained at the expense of secondary task performance when the potential consequences of instability are increased.

Behavioural observations during each condition revealed that participants, particularly OA, were observed to step away from the edge or to hold on to the safety railing between testing trials in the HE condition. These responses imply that our conditions of postural threat were perceived to be threatening by our participants. Measures of arousal confirmed that although the manipulation of environmental context was successful in increasing arousal in both the YA and OA groups, OA showed the greatest increase in arousal in the HE condition. In addition, arousal was found to increase when participants performed the BST task. This finding confirms results from earlier studies examining changes in GSC with task performance (Colman & Paivio, 1969; Johnson & Campos, 1967) and provides support that the physiological measure of arousal used in the present study provided expected results.

Interestingly, data indicated that the introduction of the secondary task adversely affected postural control in the low conditions when postural threat was minimal. Although these findings were not significant, these results are consistent with other research that indicates that the introduction of a secondary task has a negative effect on postural control (Shumway-Cook et al., 1997; Maylor & Wing, 1996). In the present study, the disruptive effect of concurrent secondary task performance on postural control was particularly evident in OA, among whom COP area measures more than doubled under dual task conditions (see Table 1, LM condition; pg. 65). However, when OA participants were asked to perform the BST task in more threatening conditions, this effect of secondary task performance disappeared. In fact, our findings suggest that postural control among OA was improved under dual-task conditions in a threatening environment. We have interpreted this finding to indicate that the prioritization of postural control is dependent upon age and the level of postural threat.

Our results suggest that a reciprocal relationship exists between secondary task performance and postural control among OA; in order for OA to improve postural stability, secondary task performance must deteriorate. Because the BST task has been shown to compete for the same cognitive resources involved in postural control (Kerr et al., 1985; Maylor & Wing, 1996), we propose that the concurrent performance of both the postural and cognitive tasks exceeded the cognitive resources available for postural control in OA in the most threatening condition. Indeed, OA have been shown to have a reduced ability to perform multiple tasks because of age-related declines in cognitive capacities (Craik & Byrd, 1982). According to the model for limited capacity of attention (Kahneman, 1973), interference from the concurrent performance of a secondary task can affect performance of the primary task, the secondary task, or both. However, a variety of internal or external factors can determine which task is affected. As has been shown in previous studies that employ a dual-task methodology, our results indicated that secondary task performance was maintained at the expense of postural control in non-threatening conditions (Shumway-Cook et al., 1997; Maylor & Wing, 1996). It is possible that, as forwarded by "the posture first hypothesis" (Shumway-Cook et al., 1997), secondary task performance in our study was prioritized in low conditions at the expense of postural control because balance was not perceived to be threatened. However, the unique finding in our study was that as the consequences of postural instability increased, the relationship between secondary task performance and postural control was altered such that balance was prioritized at the expense of cognitive task performance.

Interestingly, among YA, secondary task performance and measures of postural stability appeared to benefit from conditions of increased arousal. In particular, data from performance of the BST task revealed that performance on the BST task became significantly faster in the Edge and High conditions (see Figure 11, pg. 66). We propose that the concurrent performance of the postural and secondary tasks did not exceed the cognitive capacities of YA as it did in OA. It is possible therefore, that the effects of arousal may have had beneficial effects on secondary task performance in YA. The Yerkes-Dodson law dictates that task performance is improved with increased arousal (Yerkes & Dodson, 1908; Broadhurst, 1959). Thus, according to this theory, YA may have improved performance on the secondary task because of increased arousal. Furthermore, although not significant, our results indicated that postural control was improved in conditions of increased postural threat in YA (see Figure 14). Improved postural performance under conditions of threat has been well demonstrated in previous investigations (Brown & Frank, 1997; Carpenter et al., 1999; Adkin et al., 2000). Thus, we believe that the regulation of postural control in response to postural threat is not age-dependent; however, under dual-task conditions, OA may need to sacrifice secondary task performance to modulate postural stability.

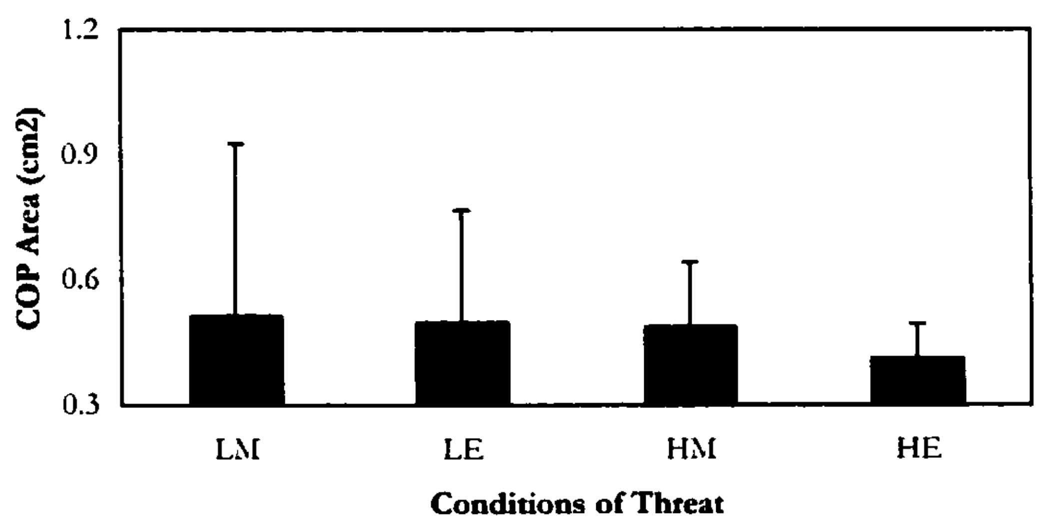

Figure 14 Effect of conditions of postural threat on Centre of Pressure area in YA. Indicating that postural stability was altered with increased postural threat. Data Presented are mean and standard error values (cm^2).

Our findings have revealed a disparity between YA and OA in the effects of secondary task performance on postural stability in conditions of environmental threat. However, it is unclear whether these findings are related to reducing fall risk. It is possible, as hypothesized by previous research on postural control in threatening conditions, that the postural adaptations observed in this study are compensatory actions that may help reduce fall risk (Brown et al., 1997; Carpenter et al., 1999; Adkin et al., 2000). However, further research is warranted to identify the ability of OA to maintain equilibrium following an external disturbance or to avoid potential threats to instability when performing a secondary task in conditions of postural threat. Furthermore, it should be stressed that the participants used in this study were healthy younger and older adults and were free from any existing anxiety about falling and/or heights. Future research is needed to assess how postural control is altered in participants with a fear of falling when placed in conditions where the potential consequences of instability are greater. Perhaps the relationship between postural control and secondary task performance is modified by situation-specific arousal. In addition, research extending beyond quasi-static postural control, such as walking, may further challenge the postural control system in conditions of increased postural threat. Indeed, recent research from our laboratory has determined that postural compensations occur during gait under conditions of postural threat (Brown, Gage, Polych, Sleik, & Winder, Submitted) and that these modifications may serve to reduce the attentional demands of locomotion (Gage et al., Submitted).

The present study has examined the effects of performing a secondary task on postural control in YA and OA when in conditions that increase the consequences of instability. Results indicated that among OA, postural control was significantly improved at the expense of secondary task performance when in conditions of the greatest postural threat. We believe that our work confirms the hypothesis forwarded by Shumway-Cook and colleagues (Shumway-Cook et al., 1997) that postural control will be prioritized over secondary task performance when the potential consequences of instability increase.

Understanding how postural control is prioritized may lead to insights regarding how to reduce falls in older adults. Based on our findings, fall risk may increase in OA who are unable, or unwilling, to compromise secondary task performance in conditions of increased postural threat. For example, maintaining equilibrium when standing on a ladder may be compromised when talking to someone on the ground. This finding could have implications for rehabilitation practitioners who often instruct patients while they are performing postural tasks (Haggard et al., 2000). Furthermore, it is unknown how postural control is altered in individuals with an existing fear of falling. Perhaps individuals with an intense fear of falling may not be able to perform a secondary task in conditions of increased postural threat. Therefore, although the present findings are important in deciphering the relationship between secondary task performance and postural control in different environmental contexts, further research is warranted to determine what actions should be taken to prevent falls in individuals who are at the most risk of falling.

GENERAL DISCUSSION

This thesis examined age-related changes in the role of cognition for postural control in conditions that altered the level of postural threat, heightened arousal, and increased the potential consequences of instability. Two different studies were completed to determine the effects of postural threat on the role of cognition for postural control: Study 1 addressed the effects of postural threat on the allocation of attention for postural control in YA and OA; Study 2 examined the effects of performing a secondary cognitive task on postural control in YA and OA when in a threatening environment. Study 2 also examined whether the prioritization of postural control over secondary task performance was altered in YA and OA in conditions of postural threat. In both studies, participants were tested in four different conditions of postural threat. Before the results of these questions can be interpreted, it was first necessary to determine if the environmental manipulations in each condition were effective in increasing arousal among participants in this study.

CHANGES IN AROUSAL IN RESPONSE TO ENVIRONMENTAL CONTEXT

Arousal was assessed using the measure of Galvanic Skin Conductance (GSC). GSC is a standard physiological indicator of arousal that determines the conductivity of the participants skin in response to changes in the amount of perspiration on the surface of the skin (Boucsein, Baltissen, & Euler, 1984). This measure has been shown to be effective in assessing arousal across a wide range of tasks (Kahneman, 1973), including determining changes in arousal in response to secondary task performance (Tursky, Schwartz, & Crider, 1970; Colman & Pavio, 1969). As expected, GSC values were lowest in the LM condition and highest in the HE condition for all participants. Because the potential consequences of falling increase as people age (Tideiksaar, 1997), it was hypothesized that greatest change in the levels of arousal would be found among the elderly group in conditions of postural threat. Results from GSC data confirmed this hypothesis and indicated that physiological arousal in OA was more affected than in YA in the HE condition (see Figure 5; pg. 43 & Figure 10; pg. 64).

In addition, participants were asked to rate their level of arousal in each condition on a scale of 1-10 (10 being most aroused). Interestingly, very few participants reported feeling anxious or nervous, even in the HE condition. Furthermore, levels of reported fear were similar for YA and OA (see Table 2). However, behavioural observations revealed that the majority of participants stepped away from the edge and held on to the safety rail between testing trials in the HE condition. These results were interpreted to indicate that participants were less comfortable in this condition than in a position that was more safe. The combination of the behavioural and physiological observations provides a strong indication that the manipulation of environmental context was sufficient in increasing arousal, particularly among OA.

Table 2 Reported levels of arousal for YA and OA in the 4 conditions of postural threat. Values indicate mean perceived "fear or anxiety about falling" for each group rated on a scale of 1 - 10 (1 not afraid at all - 10 very afraid).

Group	Age	LM	LE	HM	HE
OA	69.27	1.07	1.07	1.36	2.25
YA	22.00	1.13	1.20	1.67	2.67

CHANGES IN AROUSAL IN RESPONSE TO TASK PERFORMANCE

Research has revealed that arousal can be affected by the performance of different tasks. For instance, Colman and Pavio (1969) found that arousal, as indicated by GSC and pupil dilation, increased when participants were asked to perform a mental imagery task. These findings revealed that changes in measures of GSC and pupil dilation were indicative of cognitive activity when performing the imagery task. Results from both Studies 1 and 2 revealed significant interactions between task and testing conditions in measures of GSC. Therefore, arousal was elevated when participants anticipated the PRT task (Study 1) or when performing the BST task (Study 2) in conditions of increased postural threat. These results imply that the effects of increased postural threat on arousal may be accentuated by the performance of a secondary task. However, the overall effect of secondary task performance was task dependent, as our results did not reveal any significant differences in GSC values during the performance of the PRT but significant changes in GSC were found when performing the BST task. Thus, the levels of arousal obtained in these studies reflected changes to conditions of postural threat rather than the effects of performing a secondary task.

EFFECTS OF POSTURAL THREAT ON THE ALLOCATION OF ATTENTION FOR POSTURAL CONTROL

The findings of this thesis indicate that in conditions of postural threat, specifically the LE and HE conditions, PRT scores decreased (i.e., faster response latency). These findings were interpreted to indicate that the allocation of attention for postural control was altered in conditions of postural threat (see Figure 15). In addition, OA were observed to have the largest change in PRT scores when in the HE condition (see Figure 6; pg. 45). It is possible that participants shifted their focus of attention away from postural control and toward other environmental cues, particularly the light stimulus for the PRT task. According to Easterbrook's Hypothesis (Easterbrook, 1959) under conditions of increased arousal, individuals shift the focus of attention away from irrelevant cues to devote greater cognitive resources to more pertinent stimuli. In addition, the Yerkes-Dodson Law (Yerkes et al., 1908) dictates that increased arousal can have a beneficial effect on task performance, perhaps through mechanisms that redirect the allocation of attentional resources. According to these hypotheses, faster reaction times may have occurred because participants focused more of their attention to the PRT task and less to postural control. To achieve this shift in the allocation of attention, it is possible that compensatory alterations to postural control were implemented to reduce the cognitive demands necessary for maintaining equilibrium. To address this possibility, postural control was examined to determine if compensatory postural strategies were implemented in response to postural threat.

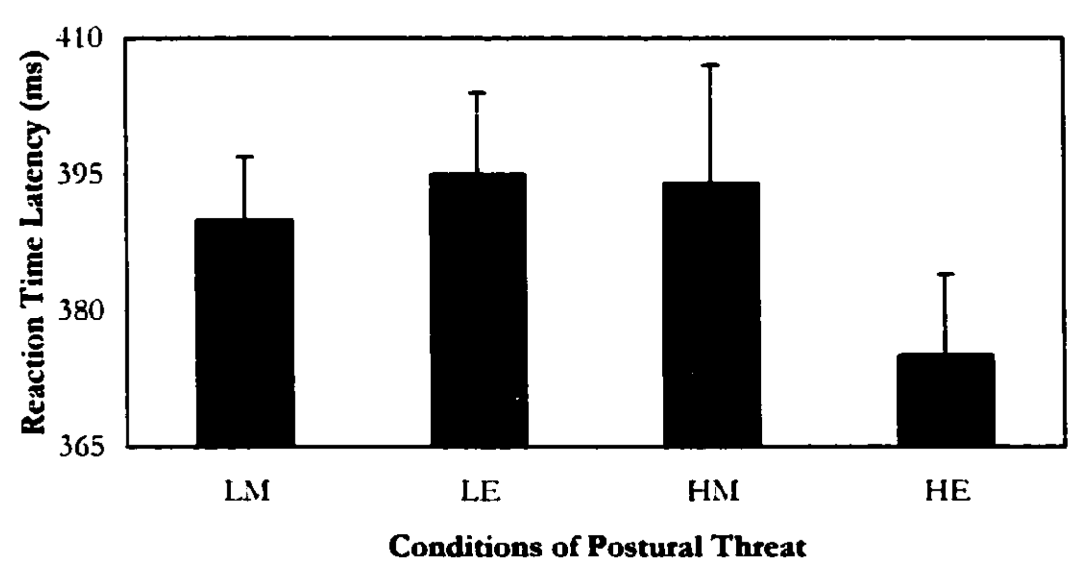

Figure 15 Probe reaction time values in each condition of postural threat. Data presented are means and standard error values (ms).

POSTURAL CHANGES UNDER THREATENING CONDITONS

Results from measures of postural control revealed that participants adjusted their COP mean position away from the edge of the platform as postural threat increased (see Figure 7; pg. 46). As suggested by other research (Brown & Frank, 1997; Adkin et al., 2000; Carpenter et al., 1999), the compensatory action of moving the COP backward, away from the edge of the platform, may allow for a greater margin of safety. The posterior shift in COP mean position in conditions of increased postural threat may also be a compensatory response to reduce the attentional demands necessary for postural control when in conditions of environmental threat. Indeed, it is possible that in other circumstances that postural adaptations may be used to conserve attention for the performance of other tasks.

Recent work from our laboratory (Gage et al., Submitted) has determined that when walking in conditions of postural threat, OA adopt more conservative gait patterns than in normal walking. From these findings it was hypothesized that the altered gait patterns observed in OA were modifications that reduced the attentional demands necessary to maintain postural control while walking. It is possible that the changes in postural control observed in this study, as well as in Study 1, serve to mediate shifts in the allocation of attention. However, it remains to be determined if the same findings observed in this thesis would occur among individuals with a fear of falling. Elderly individuals with an intense fear of falling may be unable to allocate attention to postural control because they are predisposed with concerns about their environment. On the other extreme, it is possible that attentional resources could be devoted solely to postural control and thus, an individual would be able to maintain postural stability but may not be able to recognize potential threats in their environment. Further research may provide a better indication of how the effects of postural threat affect cognitive processes for postural control in individuals with a fear of falling.

EFFECTS OF PERFORMING A SECONDARY TASK ON POSTURAL CONTROL IN A THREATENING ENVIRONMENT

Similar to work by Maylor and Wing (1996) a modified version of the Brooks Spatial Memory Task (Brooks, 1967; Brooks, 1968), was used as a continuous secondary task in this thesis. This task was employed because it has been shown to interfere with similar cognitive mechanisms involved in motor processes (Brooks, 1968) and thus, it has been shown to have a greater effect on postural stability than other tasks (Maylor & Wing, 1996). Performance scores from the BST task revealed similar findings as those collected by Brooks (1968) in his original use of the Spatial Letter Task; results from Paper 2 indicted that younger adults had a mean task performance of 12.30s compared to 11.30s obtained by Brooks over 30 years ago. However, results from this thesis also indicated that OA needed a mean of 16.07s to complete the BST task, indicating that age-related cognitive deficits, such as reduced processing speed (Salthouse et al., 1995) and short-term memory (Craik et al., 1982), may have affected OA's ability to perform this task.

Table 3 Performance of Brooks' Spatial Task (BST) in YA and OA in 3 conditions of postural threat relative to performance in LM condition; Data are presented as percent values with negative numbers indicating that task performance decreased.

Group	LE	HM	HE
YA	10.59%	8.28%	16.85%
OA	-10.80%	-12.36%	-20.68%

A comparison of cognitive performance scores between age groups revealed dramatic differences in the direction and the magnitude of change across conditions of postural threat. Specifically, our results revealed that OA required 20.68 % longer to perform the BST task in the HE condition than the LM condition, whereas YA completed the task 16.85 % faster in the same condition (see Table 3). Measures of postural control indicated that both YA and OA improved postural stability in conditions of postural threat. However, OA had the greatest reduction in COP area from the LM to the HE conditions (69.28% in OA vs. 19.69% in YA; see Figure 16). These findings were interpreted to indicate that as the potential consequences of instability increased, OA improved stability at the expense of secondary task performance. On the contrary, both postural stability and task performance in YA benefited from increased postural threat. Therefore, in OA a trade-off exists between secondary task performance and postural control in conditions where the potential costs of falling are greater.

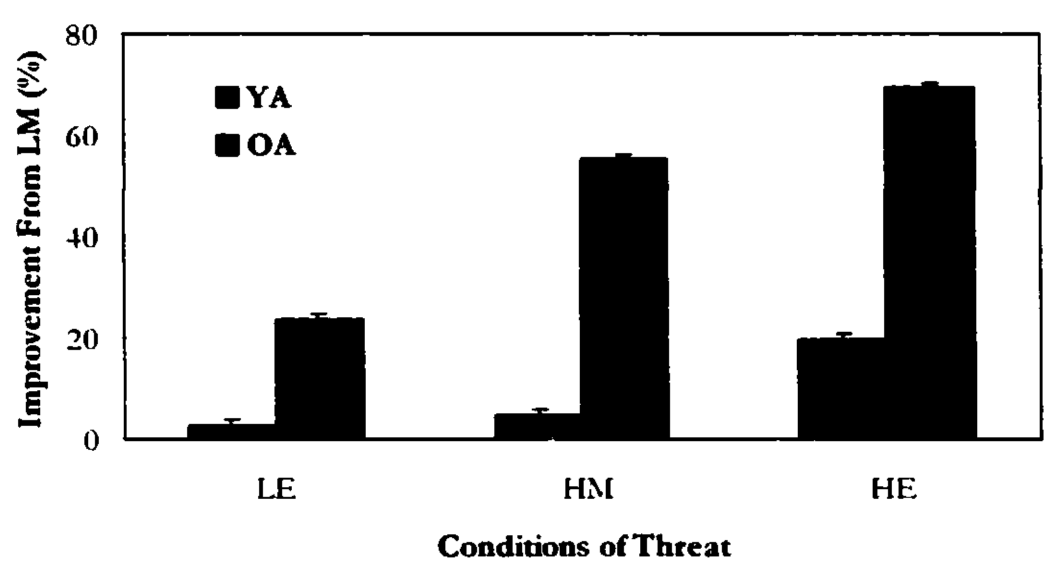

Figure 16 Alterations in postural stability as indicated by COP area in YA and OA revealing that the greatest improvement in stability in response to postural threat occurred in OA. Values represent mean percent change from LM condition.

THE RELATIONSHIP BETWEEN POSTURAL CONTROL AND SECONDARY TASK PERFORMANCE: THE PRIORITIZATION INDEX

The goal of Study 2 in this thesis was to examine changes in the relationship between secondary task performance and postural control in conditions of postural threat. Previous research using a dual-task paradigm has established that postural control suffers when performing a cognitively demanding secondary task (Maylor & Wing, 1996; Shumway-Cook, et al., 1997). However, the "posture first hypothesis" (Shumway-Cook et al.) dictates that postural control is prioritized over secondary task performance under conditions of postural threat, predicting that the findings of Maylor and Wing and Shumway-Cook and colleagues would be altered if participants perceived a threat to their balance. Indeed, other research has indicated that postural stability is improved under conditions of postural threat (Brown and Frank, 1997; Carpenter et al., 1999; Adkin et al., 2000) but it was unknown if the relationship between secondary task performance and postural control would change under similar conditions. Therefore to determine if postural control is prioritized over secondary task performance under conditions of postural threat, changes in postural control and secondary task performance were examined in YA and OA under threatening environmental conditions.

Although findings revealed a dichotomy between changes in the cognitive performance of YA and OA, both groups revealed significant improvements in postural stability in conditions of postural threat. Findings from research by Carpenter et al. (1999) and Adkin et al. (2000) have revealed that younger adults adopt a stiffening strategy that reduces COP variability in response to conditions of postural threat. A stiffening strategy may serve to improve response times to unexpected postural perturbations by improving reflexive muscular responses around the ankle joint (Winter et al., 1990) particularly when combined with a more posterior COP mean position (Brown & Frank, 1997). Although a stiffening strategy that improves postural stability and increases joint stiffness has been suggested, it remains to be determined whether this strategy occurs as a conscious process. For example, Bond and Morris (2000) have revealed that individuals with Parkinson's disease appear to be more stable than "normal" controls; this difference in stability may be mediated in those with Parkinson's disease by directing greater attentional resources to postural control to ensure that equilibrium is maintained.

A stiffening strategy may serve to reduce the attentional demands of postural control in conditions of postural threat. This possibility may provide an explanation for the improved task performance that was observed in YA in Study 2. However, a surplus of attentional demands would not explain the performance decline on the BST task in OA. If a stiffening strategy reduced cognitive demands for postural control, it would be expected that greater cognitive resources would be available for secondary task performance and therefore, task performance would improve. However, the findings of this thesis did not support this notion, as task performance in OA declined when postural stability improved. In addition, findings from Study 1 indicated that postural stability decreased when attentional resources were directed away from postural control. Thus, it is possible that age-related differences in cognitive mechanisms, such as reduced attentional capacity (Craik & Byrd, 1982) and slowed processing speed (Salthouse, 1995), were responsible for the divergent results observed between YA and OA in this study. Indeed, the age-related differences observed in baseline performance of the BST tasks in Study 2 revealed that OA had reduced performance on the BST task than YA, confirming that age-related cognitive deficits affected cognitive task performance. Considering these age-related deficits, it is possible that the combined effort of improving postural stability and performing a secondary task in conditions of increased arousal may have exceeded the available attentional capacities of OA.

Similar to the findings from this thesis, previous studies have found that both postural control and secondary task performance can be altered under dual-task conditions. For instance, Lindenberger and colleagues (Li et al., In Press; Lindenberger et al., 2000) monitored changes in walking patterns in relation to performance of a secondary cognitive task in younger, middle-aged, and older adults. These authors found that in addition to reduced performance on the secondary task, walking speed and accuracy declined in older adults. These results indicate that it was more difficult for older adults to walk while concurrently performing a secondary cognitive task. Research by Haggard and colleagues (2000) determined that individuals with cognitive deficits resulting from neurological damage had significantly reduced walking speeds and secondary task performance under dual-task conditions. These studies reveal that changes in cognitive processes, either by age-related factors or neurological insults, can have a severe impact on an individual's ability to perform in dual-task conditions. Findings from Study 2 differ from previous work because the constraints of the environmental context in this thesis necessitated that participants maintained postural control. Based on the findings of this thesis, it is possible that under conditions that increase the possibility for falling, such as in tests of postural perturbation, performance on a secondary task would be significantly compromised (Brown et al., 1999).

IMPLICATIONS FOR FEAR OF FALLING

The younger and older adults who participated in this thesis were healthy and free from any contraindications that could affect their ability to maintain postural control. In addition, none of the participants reported any aversions to heights or reported a fear of falling. Thus, it is difficult to substantiate any conclusions on the relationship between postural control and secondary task performance in individuals with a fear of falling. However, based on the findings of this thesis predictions can be put forward that may direct future research.

Results from Study 1 indicated that the focus of attention was shifted from postural control to external environmental cues in conditions of postural threat. A fear of falling may exaggerate changes in the allocation of attention. For instance, the focus of attention may be excessively directed to external cues in people with a fear of falling because there may be a greater concern to observe potential threats in the environment. However, this response may be counterproductive in preventing falls because postural compensations that permit changes in the allocation of attention could potentially disrupt equilibrium. On the contrary, another possibility is that the focus of attention could be directed more toward postural control in individuals with a fear of falling. Directing more attention to postural control may function to improve balance in those who are at a greater risk of falling. Further work is needed to determine if devoting more attentional resources to postural control would have beneficial effects on postural control. In addition, directing too much attention away from observing external cues may diminish the ability to perceive potential threats in the environment that could perturb balance. For instance, older adults who are preoccupied with thinking about their balance may be more likely to trip on an unexpected obstacle than individuals who are able to adequately allocate attention to maintaining balance and observing changes in the environment.

Results from Study 2 indicated that the ability to divide attention between two concurrent tasks is altered in older adults under conditions of postural threat. I predict that individuals with a fear of falling would be less able (or unable) to perform the secondary task in conditions of postural threat because the prioritization of postural control would compete for attentional resources. It would be important to determine if individuals with a fear of falling have a reduced capacity for performing secondary tasks. If those with a fear of falling had reduced cognitive capacities for performing concurrent tasks, it is possible that the performance of secondary cognitive tasks, as well as postural control, could diminish. Thus, conditions that elevate arousal by increasing the potential consequences of instability could have negative repercussions on the ability to maintain postural control in individuals with a fear of falling. Future research is warranted to determine if secondary task performance is altered in individuals with a fear of falling. This research would be beneficial in helping determine how fear alters the risk of falling in dual-task conditions.

RESEARCH APPLICATIONS

The results of Study 2 indicate that the relationship between postural control and secondary cognitive task performance is altered under conditions of postural threat. Specifically, it appears that when the consequences of falling are more severe, such as it may be in older adults, postural control is prioritized over performing other tasks. The findings of this thesis have several important implications for OA, particularly in conditions where balance may be threatened. According to the findings of this thesis, balance would be prioritized over performing other tasks if an OA were standing on a stepladder, a situation that would increase the potential consequences of instability.

The constraints of our testing protocol did not emphasize the performance of one task over another; in the controlled environment of the laboratory, participants were allowed to choose, either consciously or unconsciously, which task to prioritize. Therefore, postural control may suffer in dual-task conditions if the performance of a secondary task takes precedence over postural control. In rehabilitation, therapists often need to direct the patient while they are engaged in postural activities. Attending to directions or instructions from a therapist while attempting to perform a postural task may actually initiate a loss of balance in individuals with cognitive deficits (Haggard et al., 2000).

The allocation of attention for performing different tasks is most likely more complex in the real world than under the controlled conditions of the laboratory (Shumway-Cook et al., 1997). Many factors may alter the prioritization of one task over another. However, I predict that when the consequences of instability are increased, such as when negotiating slippery surfaces, the allocation of attentional resources necessary for postural control will be prioritized over the allocation of attention for performing other tasks. A change in the allocation of attention can often be observed in elderly individuals who need to stop talking when walking on a slippery surface or when walking down stairs.

LIMITATIONS

The participants used in this thesis were healthy and fit older adults who were free from any contraindications that would affect postural control. Although we can be confident that changes in postural control were not caused by other factors, conclusions based on this thesis cannot be extended to individuals with who suffer from neurological impairment or who may be at risk of falling. Furthermore, none of the participants reported any concerns regarding a fear of heights or a fear of falling. Thus, although the different conditions presented in this study were found to increase physiological arousal the manipulations may not have been sufficient to actually create a "fear of falling" in the participants. In addition, all participants wore a safety harness that would have prevented an actual fall. Therefore, it is possible that the perceived threat of falling was also reduced because the risk of injury was unlikely, even in the most threatening conditions.

It should also be stressed that changes in arousal from conditions of environmental threat may not be equivalent to changes in arousal from anxiety from reduced perceived balance ability. Many older adults experience anxiety from a reduced perceived confidence in their balance ability (Tideiksaar, 1997) and thus, changes in task performance in these individuals may not necessarily follow the same pattern observed in this thesis. Future research that tested dual-task performance in threatening conditions in individuals with a fear of falling would help identify potential fall risk factors in this population.

Finally, results from measures of changes to cognitive demands related to postural control may be influenced by a variety of factors. For instance, performance on the PRT task may be affected by boredom or distractions. Reaction time trials were blocked to minimize this possibility; thus, individuals were able to focus on performing the reaction time task. In addition, differences in memory capabilities may have influenced between group differences (Craik and Byrd, 1982). Specifically in relation to Study 2, it is possible that age-related differences in attentional capacities in YA and OA may have affected the results observed. Perhaps the cognitive requirements for implementing strategies that improve postural control were not as demanding in YA as they were for OA. Indeed, the change in postural stability that was observed in OA was much more dramatic than that of YA (69.28% in OA vs. 19.69% in YA). These findings indicate that for OA, more cognitive resources may be needed for improving postural stability. Thus, the more that stability is improved the greater the cognitive resources that are needed to implement compensatory actions to achieve improved stability. To account for age related differences in task performance, all cognitive data were analysed with an Analysis of Covariance, using baseline performance while sitting as a covariate. Instructions during the collection of these data were explicit in not emphasizing the performance of one task over another (i.e., balance over secondary task performance). However, it is possible that many individuals felt the need to perform as best as they could on one particular task. Any attempts to perform one task over another would most likely not be specific to one age group; therefore the effects of task preference would have only resulted in reducing the magnitude of differences in our findings.

CONCLUSION

It was determined that postural threat has a significant impact on the cognitive processes related to postural control. The findings of this thesis revealed age-related differences in the cognitive processes for postural control under conditions of environmental threat. Results indicated that under conditions of increased arousal, the focus of cognitive resources was shifted away from postural control and towards external environmental cues. This finding may indicate an innate response to heighten awareness of one's surroundings when there is a risk of falling. Results revealed that in conditions of increased postural threat, PRT values became faster, indicating that less cognitive resources were necessary for postural control. Interestingly, measures of postural control indicated that postural compensations are produced that may reduce the risk of falling by creating a greater margin of safety from the source of threat (i.e., the edge of the platform). These postural compensations may also serve to facilitate changes in the attentional demands of postural control to permit greater cognitive resources to be devoted to detecting potential threats in the environment.

The findings of this thesis have also suggested that postural threat alters the prioritization of postural control under dual-task conditions. The effects of arousal appeared to benefit both postural control and secondary task performance in YA. However, OA were shown to improve postural stability only at the expense of secondary task performance. These findings support the "posture first hypothesis" that proposes that postural control will be maintained at the expense of secondary task performance when the potential consequences of instability increase (Shumway-Cook et al., 1997). Indeed, a fall can be a much more deleterious event for an OA and thus, the need to prevent a fall would be of primary concern for this population.

The findings of this thesis did reveal that in OA postural stability was dramatically improved in conditions of postural threat but only at the expense of secondary task performance, particularly among OA. These findings may provide some insight into the underlying mechanisms involved in maintaining postural control in different environmental conditions. This thesis also provides evidence that conditions of postural threat can alter factors related to postural control in healthy older adults who do not have a pre-existing fear of falling. However, it should be cautioned that although our results indicate that conditions of postural threat appear to have a beneficial effect on postural control, it does not warrant the conclusion that people are less likely to fall when they experience anxiety from environmental conditions. Future work is needed to determine how factors that may increase fall risk, such as a fear of falling, frailty, or cognitive impairment, can affect the ability to preserve postural stability in conditions of postural threat.

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APPENDIX 1

The Falls History Questionnaire used to assess participants perceptions about falling and their history of falls.

1) Are you afraid of falling during your daily activities?

Y				Sometimes					N
(I am scared to do many things)									(I never fear falling)
10	9	8	7	6	5	4	3	2	1

2) Are you afraid of heights? Y N

3) Are there any circumstances that make you feel nervous about losing your balance or may be a cause for a fear of heights? If so what are they?

4) When was the last time you lost your balance or fell?

5) If you did fall what was the cause of the fall?

6) Are there any conditions or medications that you believe may affect your balance?

APPENDIX 2

The Gait Efficacy Scale (GES) and the Activities Specific Balance Confidence Scale (ABC) used to assess participants confidence in performing specific daily activities.

1) How would you rate your balance?

    5. excellent   4. very good   3. good   2. fair   1. poor

2) How much does your balance interfere with your physical activities or general movement?

    5. never   4. rarely   3. sometimes   2. usually   1. always

3) How often do you engage in exercise?

    5. daily   4. 4-6x/week   3. 1-3x/week   2. monthly   1. never

4) How often are you afraid of falling?

    5. never   4. rarely   3. sometimes   2. usually   1. always

5) How confident are you that you can walk about your house without losing your balance or falling? (same scale used on all subsequent questions)

10	9	8	7	6	5	4	3	2	1
very confident				confident if I am careful				not at all confident	

6) How confident are you that you can prepare your meals without losing your balance or falling?

7) How confident are you that you can get on and off the toilet without lsoingyour balance or falling?

8) How confident are you that you can get on and off the toilet without losing your balance or falling?

9) How confident are you that you can get dressed without losing your balance or falling?

10) How confident are you that you can get in and out of a chair without losing your balance or falling?

11) How confident are you that you can answer the door or phone without losing your balance or falling?

12) How confident are you that you can get in and out of bed without losing your balance or falling?

13) How confident are you that you can take a bath (or shower) without losing your balance or falling?

14) How confident are you that you can climb a stepstool without losing your balance or falling?

15) How confident are you that you can go to the bathroom at night without losing your balance or falling?

16) How confident are you that you can walk outside at night without losing your balance and falling?

17) How confident are you that you can go grocery shopping without losing your balance or falling?

18) How confident are you that you can go outside and garden without losing your balance and falling?

19) How confident are you that you can go upstairs with a handrail without losing your balance or falling?

20) How confident are you that you can go down stairs with a handrail without losing your balance or falling?

21) How confident are you that you can go up stairs without a handrail without losing your balance or falling?

22) How confident are you that you can go down stairs without a handrail without losing your balance or falling?

23) How confident are you that you can use and escalator to go up?

24) How confident are you that you can use and escalator to go down?

25) How confident are you that you can get off an escalator easily?

26) How confident are you that you can get on an escalator easily?

APPENDIX 3

Statistical summary for Study 1 2X2X2X2 RM ANOVA for mean GSC (ΦS).

Measure	F Value	Degrees of Freedom	p Value
Task	F=0.002	1,14	0.968
Height	F=25.897	1,14	0.000
Position	F=4.232	1,14	0.059
Age	F=0.343	1,14	0.567
Task X Age	F=0.259	1,14	0.619
Task X Height	F=0.326	1,14	0.577
Task X Height X Age	F=7.116	1,14	0.018
Task X Position	F=4.338	1,14	0.056
Task X Position X Age	F=1.603	1,14	0.226
Task X Height X Position	F=0.134	1,14	0.719
Task X Height X Position X Age	F=0.066	1,14	0.801
Height X Age	F=2.509	1,14	0.136
Position X Age	F=3.738	1,14	0.074
Height X Position	F=5.502	1,14	0.034
Height X Position X Age	F=3.417	1,14	0.086

APPENDIX 4

a) Statistical summary for Study 1 2X2X2 RM ANCOVA for mean PRT (ms).

Measure	F Value	Degrees of Freedom	p Value
Height	F=0.271	1,26	0.607
Position	F=8.826	1,26	0.006
Age	F=0.025	1,26	0.876
Height X Age	F=1.338	1,26	0.258
Position X Age	F=0.079	1,26	0.780
Height X Position	F=7.477	1,26	0.011
Height X Position X Age	F=0.484	1,26	0.493

b) Statistical summary for Study 1 2X2 RM ANCOVA for mean PRT (ms) for YA only.

Measure	F Value	Degrees of Freedom	p Value
Height	F=0.107	1,12	0.749
Position	F=2.214	1,12	0.163
Height X Position	F=0.084	1,12	0.777

c) Statistical summary for Study 1 2X2 RM ANCOVA for mean PRT (ms) for OA only.

Measure	F Value	Degrees of Freedom	p value
Height	F=0.219	1,13	0.648
Position	F=6.007	1,13	0.029
Height X Position	F=13.439	1,13	0.003

APPENDIX 5

Statistical summary for Sudy 1 2X2X2X2 RM ANOVA for COPx mean position as a percentage of BOS.

Measure	**F Value**	**Degrees of Freedom**	**p Value**
Task	F=0.002	1,27	0.963
Height	F=10.435	1,27	0.003
Position	F=24.670	1,27	0.000
Age	F=4.578	1,27	0.042
Height X Position X Age	F=0.020	1,27	0.889

APPENDIX 6

Statistical summary for Study 1 2X2X2X2 RM ANOVA for COP Area (cm^2).

Measure	F Value	Degrees of Freedom	p Value
Task	F=2.937	1,27	0.098
Height	F=0.035	1,27	0.853
Position	F=4.610	1,27	0.041
Age	F=7.587	1,27	0.010