POSTURAL CONTROL IS MODIFIED BY AN INTERACTION OF PSYCHOLOGICAL AND PHYSIOLOGICAL FACTORS

By

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ABSTRACT

This thesis investigated the effects of balance confidence on postural control strategies for maintaining upright stance. Two studies were conducted to examine this relationship in healthy young adults. Balance confidence was modified through the introduction of a threat to posture: standing or voluntarily rising to the toes when positioned away from or at the edge of a platform raised to different surface heights above ground level. For both tasks, the central nervous system (CNS) adjusted the postural response to the level of the postural threat. When standing, amplitude of postural sway decreased progressively while frequency increased progressively as postural threat was increased steadily. Furthermore, this postural response was influenced by the order in which the threat to posture was experienced. For the rise to toes task, the rate and magnitude of the anticipatory postural response was significantly reduced for the most threatening compared to the least threatening condition. These changes in anticipatory postural control resulted in a slower acceleration and reduced forward movement of the centre of mass (COM) to the new position of support over the toes. In both instances, it appeared that the CNS modified control of posture to minimize the disturbance to the body COM; this cautious approach provided for a greater margin of safety especially when the consequences of instability were high. In addition to these changes in postural control, physiological arousal and perceived anxiety increased while perceived confidence and perceived stability decreased when performing the balance tests under more threatening conditions.

The third study investigated the effects of balance confidence on postural control for individuals with Parkinson's disease (PD). A series of eight standing balance tasks were performed; each task provided a different threat to posture. For example, patients were asked to stand with eyes open or closed, feet apart or close together, on a normal or foam support surface or with the possibility of being pushed or pulled off balance. The results suggested that individuals with PD who had less confidence in their ability to perform activities of daily living (ADLs) without falling reported less confidence and more anxiety, felt less stable and demonstrated greater postural sway on the balance tests compared to those individuals who had more confidence. Although significantly related

to the severity of the disease, a measure of balance confidence provided added information to explain variation in balance performance. This observation was especially true for the more challenging standing tests, such as standing feet apart with eyes closed or standing feet together with eyes open or eyes closed.

The results of this thesis provide converging evidence identifying balance confidence as a key psychological modulator of postural control. Balance confidence influences the appraisal of postural threat and psychological and physiological responses to this threat. Balance confidence also influences behavioural outcomes, including strategies for postural control. This body of research emphasizes the importance of identifying both psychological and physiological influences on postural control strategies for maintaining upright stance. Although alterations in strategies for postural control may result from an underlying physiological cause, psychological factors, such as fear of falling or low balance confidence, may also contribute to these changes. An understanding of how psychological factors modify strategies for postural control provides direction for balance assessment and fall prevention for individuals who are afraid of falling.

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DEDICATION

For teaching me that I could accomplish anything I set out to do - it is to my family that the thesis is dedicated.

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CHAPTER 1

INTRODUCTION

The control of upright stance is an essential requirement for the successful performance of an extensive range of human movements and activities. The central nervous system (CNS) generates precisely scaled and timed postural adjustments in order to maintain or recover upright stance. These adjustments, integrating a rich source of sensory information, are matched to the parameters associated with the task and are modified by the context in which the task is performed (Horak and Macpherson 1996; Massion 1992, 1994). Unquestionably, age and pathology can disrupt the organization of postural adjustments at several levels, threatening the control of balance and increasing the risk of falls (Alexander 1994; Horak 1997; Horak et al. 1989, 1997; Maki and McIlroy 1996; Morris 2000; Rogers 1996; Tang and Woollacott 1996; Woollacott 2000). Older adults and individuals with balance disorders may experience reduced confidence or efficacy in their capability to perform specific movements or engage in certain activities, a phenomena commonly referred to as fear of falling (Bandura 1977, 1982 and 1997; King and Tinetti 1995; Maddux 1995; Powell and Myers, 1995; Tinetti et al. 1990; Tinetti and Powell 1993). A task that once was performed without concern may now be viewed as a significant challenge due to actual or perceived alterations in the postural adjustments used to maintain or recover upright stance. The goal of this thesis was to investigate the effects of psychological factors, such as balance confidence, on postural control strategies for upright stance. This is an area of research that has both fundamental and clinical relevance and remains relatively unexplored (Alexander at al. 1994).

Falls and fear of falling in the elderly

The high incidence of falls in the elderly is a key health issue. Each year in the community, it is estimated that approximately one-third to one-half of individuals over the age of 65 experience a fall (Berg et al. 1997; Blake et al. 1988; Downton and Andrews 1990; Nevitt et al. 1989; Prudham and Evans 1981; Tinetti et al. 1988). For an older adult, significant physical injury as well as psychological consequences may result from a fall event; these complications can modify behaviour presenting a considerable challenge for maintaining independence and quality of life (King and Tinetti 1995). For example, older adults frequently report fear of falling. Prevalence rates vary, but approximately one-half of older adults who have previously experienced a fall and even one-third of older adults who have never reported a fall acknowledge fear of falling (Arfken et al. 1994; Downton and Andrews 1990; Niino et al. 2000; Tinetti et al. 1988, 1994; Vellas et al. 1997; Walker and Howland 1991). Older adults alter their behaviour due to this fear of future falls. Fear of falling has been associated with balance and gait impairment, restriction of activity, loss of independence and reduced quality of life (Arfken et al. 1994; Cumming et al. 2000; Howland et al. 1998; Lachman et al. 1998; Tinetti et al. 1988; 1994; Vellas et al. 1997; Walker and Howland 1991). Furthermore, fear of falling is related to an increased risk of falls (Cumming et al. 2000). A possible explanation for this association is that fear of falling modifies strategies for postural control, which in turn lead to increased fall risk. Alternatively, falling or alterations in postural control may produce the fear of falling (Hill et al. 1996; Maki et al. 1991).

The identification of older adults who may be at risk for falls provides a significant challenge for health care professionals and researchers (Tinetti 1994). This task is complicated by complex interactions between multiple risk factors that predispose older adults to falls. For example, age-related changes in the postural control system, disease processes, such as Parkinson's disease (PD), and environmental factors are significant contributing factors for falls (Downton 1996; Lord et al. 1991; Rubenstein et al. 1988; Sattin 1992). The prevalence of fear of falling in the elderly and the behavioural modifications that result from this fear highlight the need to consider fear of falling or low balance confidence as a key psychological modulator of postural control and a contributing factor for falls.

Defining fear of falling as low balance confidence

One challenge for identifying the effects of fear of falling on behaviour, especially the control of posture, in older adults and individuals with balance disorders lies in the definition of fear of falling and its measurement. The term "fear of falling" is used widely clinically and in the research literature to describe a worry about falling that causes an individual to start to avoid activities that they are capable of performing (Tinetti and Powell 1993). However, different approaches have been used to identify older adults who are fearful of falling. Frequently, researchers have asked the question "Are you afraid or fearful of falling?" The answers to this question range from very much to a little or somewhat to not at all afraid of falling. The response to this question provides a general estimate of fear of falling and may be influenced by only a few activities that the individual finds extremely challenging. Fear of falling estimates for specific tasks are not addressed using this approach; for example, performing more challenging tasks may induce a greater degree of fear of falling than other less challenging tasks. Thus, a dichotomous measure may be less able to discriminate between fearful and non-fearful older adults. The limitations to this approach have been acknowledged in the literature (Lachman et al. 1998; Powell and Myers 1995; Tinetti et al. 1990); however, due to the relative ease of administration of the question, the approach is still used extensively to identify those older adults who are fearful of falling.

As an alternative to this approach, Tinetti and colleagues (1990) developed the Falls Efficacy Scale (FES) to measure fear of falling on a continuous scale; fear of falling was defined as low perceived self-efficacy for avoiding falls during activities of daily living (ADLs). This definition was based on self-efficacy theory or an individual's perceived capabilities or confidence to perform a specific activity (Bandura 1977, 1982 and 1997; Maddux 1995). On this ten-point scale, individuals rate the confidence in their ability to perform ten ADLs without falling, such as walking around the house or getting in and out of a chair or bed. The results from the administration of the FES to community living individuals 72 years and older showed that a continuous measure of balance efficacy was related to the performance of ADLs, physical and social functioning whereas a dichotomous measure of fear of falling (i.e., yes or no response) was not (Tinetti et al. 1994). Thus, the FES may estimate behaviour more accurately and provide a better measurement tool for examining the relationship between fear of falling and behavioural outcomes.

Since its introduction as a tool to measure fear of falling on a continuous scale, the FES has been modified in an attempt to make the scale more specific to a greater range of individuals and their various levels of functioning. The Activities-specific Balance Confidence (ABC) scale, based on the same principles of the FES, was designed to examine balance confidence using more situation-specific balance activities within a larger range of difficulty (Powell and Myers 1995; Myers et al. 1996). On this scale, participants rate the degree of confidence they have in their ability to complete sixteen ADLs without falling. The scale ranges from 0 % reflecting no confidence to 100 % reflecting complete confidence. The scale was designed specifically to detect low balance confidence in individuals of different functional levels, especially those individuals who may be more active. The scale includes both walking and reaching-oriented activities that challenge postural control and activities that are performed both indoors and outdoors. Furthermore, Hill and colleagues (1996) developed a modified FES which included the ten items from the original scale plus 4 additional items that involve an increased challenge to balance: taking public transport, crossing roads, performing light gardening or hanging out the wash, and using the front or rear steps at home. The findings from the ABC and modified FES provide evidence for the importance of assessing balance confidence in a task-specific manner. Balance efficacy may be highly related to the difficulty of the postural task and the environment in which the task is performed (Maddux 1995). For example, some individuals may feel most comfortable when asked about their confidence in their ability to walk around the house. However, these same individuals may feel uncomfortable and report diminished confidence when walking outside or in a crowd or in other challenging situations. Thus, an examination of balance efficacy effects on multiple postural tasks is essential. It is this task-specific information that is not gained with a more general measure of fear of falling.

Furthermore, it appears that a continuous measure of balance efficacy for a number of different tasks of varying levels of difficulty may provide a better estimate of actual fear of falling than a generalized fear of falling question. The challenge for researchers and clinicians is to develop accurate and detailed assessment techniques for the identification of fear of falling or low balance efficacy in older adults and individuals with balance disorders. The difficulty in defining the entity "fear of falling" reveals its complex nature.

Impact of fear of falling on control of posture and gait in the elderly

The exploration of the relationship between fear of falling and postural control is difficult due to the complex multidimensional nature of both entities. Alterations in postural control strategies in the elderly or individuals with balance disorders may predispose them to falling. Impaired postural control is normally attributed to underlying physiological changes; however, psychological factors such as fear of falling may directly or indirectly influence postural control ultimately leading to falls. Despite the prevalence of fear of falling in the elderly and individuals with balance disorders, research directed toward establishing a relationship between this fear and postural control is limited. The studies that have been conducted show that an association exists between fear of falling or balance confidence and postural control; however, no study has yet determined a casual relationship between fear of falling and performance on balance tests. For example, the fear of falling may result from actual or perceived changes in the individual's ability to control their posture or fear of falling may act to modify postural control strategies leading to falls (Hill et al. 1996; Maki et al. 1991,1994).

Several studies have reported an association between fear of falling and postural control in the elderly. Maki and colleagues (1991, 1994) observed that older adults who reported fear of falling displayed larger amplitude of postural sway on a spontaneous sway test when blindfolded, had reduced centre of pressure (COP) movement on medial-lateral eyes-open induced-sway tests and had shorter durations when standing on one leg compared to those who did not report fear of falling. In these studies, an individual was identified as fearful if they answered "very much" or "somewhat" to the question "Are you afraid of falling?" Baloh et al. (1994) observed that older adults who reported fear of falling had significantly higher sway velocity values for dynamic posturography tests (platform moved linearly or tilted in anterior-posterior or medial-lateral directions) performed with eyes closed compared to those who did not report a fear of falling. No differences in sway velocity were observed between fearful and non-fearful groups for static posturography tests (platform not moved) with eyes open or closed or dynamic posturography tests with eyes open. Furthermore, Hughes and colleagues (1996) observed, in older adults, a moderate relationship between several measures of postural sway, including amplitude and area measures, and the mean score reported for the FES. This result suggests that older adults who display larger postural sway also report less confidence in their ability to perform ADLs; this relationship was more evident when standing for 30 s with eyes closed compared to eyes open. Myers and colleagues (1996) demonstrated an association between physical ability and perceived capabilities. Individuals who reported low confidence on the ABC scale had increased amplitude of COP during quiet standing tests. Thus, it appears that postural sway is greater on specific postural tests, especially those that challenge balance control in fearful older adults. These findings illustrate the possible confound of fear of falling or low balance confidence on the control of posture.

An association between fear of falling and gait performance has also been reported. Maki (1997) showed that older adults who reported a fear of falling reduced their stride length and velocity and prolonged the time they spent in double support during unrestricted walking compared to those older adults who did not report a fear of falling. Rosengren and colleagues (1998) evaluated gait efficacy in older adults using a revised version of the Gait Efficacy Scale (McAuley et al. 1997); this scale provides an estimate of the confidence in the capability to walk under challenging conditions such as walking up and down stairs or stepping over obstacles. These researchers observed that gait efficacy was related to changes in gait performance on an obstacle avoidance task; older adults reporting low gait efficacy had slower gait speeds. Myers et al. (1996) showed that individuals who reported less confidence in their ability to perform ADLs without falling displayed slower walking speeds. These findings suggest that the CNS selects a more cautious strategy when confidence in the ability to navigate through the environment is reduced.

The results of these studies illustrate the possible confounding effects of fear of falling or low balance confidence on postural control and gait in the elderly. This literature highlights the need for further understanding of the role of fear or balance confidence on postural control.

Impact of fear of falling on control of posture in individuals with balance problems

The impact of fear of falling may be especially significant for individuals with balance problems. Research has been directed toward establishing a link between balance and anxiety for patients suffering from vestibular problems (Brandt 1996; Sklare et al. 2001; Yardley and Hallam 1996). For example, Burker et al. (1995) observed that poorer performance when standing feet together with eyes closed was related to reports of higher fear of falling in dizzy elderly. Krafczyk et al. (1999) observed that patients with phobic postural vertigo adopted a tighter control of posture characterized by smaller amplitude and higher frequency postural sway compared to normal. These researchers argued that the postural control modifications were due to an increased anxiety in the patient group compared to normal individuals. Lepicard et al. (2000) used an animal model to illustrate anxiety-related effects on postural control. Balance performance was markedly different for an anxious strain of mice compared to a non-anxious strain of mice; anxious mice demonstrated a greater number of falls and greater instability, as well as different trunk and tail positions that reflected a less stable posture on a challenging test of balance. These studies emphasize the association between balance and anxiety in both human and animal models; the organization of the pathways and structures in the nervous system responsible for this association is a subject of recent attention (Balaban and Thayer 2001).

Fewer studies have been conducted to examine the relationship between fear of falling and postural control in other populations known to have balance problems. The prevalence and influence of fear of falling on physical function has been established for individuals with rheumatoid arthritis (Fessel and Nevitt 1997) and individuals who have undergone hip replacement surgery (Ingemarsson et al. 2000; Petrella et al. 2000). However, the effects of fear of falling or low balance confidence on postural control have not been examined in individuals diagnosed with Parkinson's disease (PD) or other neurological disorders such as stroke. An investigation of fear of falling effects in populations known to have balance and gait problems may provide valuable information for identifying those individuals who are at the greatest risk for falls.

Balance efficacy influences the appraisal of postural threat

A balance efficacy postural control model is proposed to explain the effects of psychological and physiological factors and their interactions on postural control (Figure 1.1). Previous experience, age and pathology can influence balance confidence; this confidence will influence the appraisal of a threat to posture. The presence of a threat to posture may result in a cascade of physiological or psychological changes altering the expression of a specific behaviour or response. The threat to posture may present itself as a challenging or difficult postural task or activity, such as standing on one leg, standing on a chair to reach for an item located above head level or walking outside in slippery conditions. The principle is that the postural threat represents a significant consequence for the older adult such as a risk for injury should a fall result. The perceived postural threat can induce or create changes in level of anxiety or fear. Anxiety or fear is a normal reaction to a threatening situation and results from the appraisal of danger in that given situation (LeDoux 1998). A great deal of research has investigated the anxiety and fear responses in specific situations and the structures and pathways in the nervous system, such as the amygdala, responsible for these changes (Davis 1992, 1998; Lang et al. 1998, 2000; LeDoux 1996, 1998; Wilken et al. 1999, 2000). The degree of threat or danger associated with a task or situation will determine the anxiety or fear response (Rapee 1997; Riskind 1997). Anxiety and fear responses can be placed on a continuum; with fear an extreme extension of anxious behaviour (Davis 1992). However, anxiety appears to be associated with the anticipation of a threat whereas fear is the response to the threat when it is actually present (Davis 1992). The amount of threat associated with the balance task will be dictated by an individual's balance efficacy, which itself is influenced by age-related changes in postural control, pathology, environmental factors and also traits unique to the individual (Maddux 1995). Furthermore, the appraisal of the ability to control or cope with the situation can influence the response to the threat to posture (Cohen et al. 1997; Maddux 1995). Thus, level of balance efficacy and the presence of a threat to posture would interact to influence the actual expression of the fear or anxiety response.

The threat itself or the changes in fear and anxiety perceptions may be accompanied by changes in physiological arousal (Whyte 1992). Anxiety or fear can produce a complex pattern of behavioural changes including increases in autonomic activity such as heart rate and blood pressure (Cohen et al. 1997; Davis 1992). The increases in physiological arousal may further heighten perceptions of fear and anxiety, although this is not always the case (Cohen et al. 1997). Of note, an association between increased arousal and changes in postural control has been observed. For example, Maki and McIlroy (1996) observed that when healthy young subjects attended to a cognitive task, physiological arousal was increased; the increase in arousal was associated with changes in postural control including leaning further forward and increased tibialis anterior muscle activity. Furthermore, Fridlund et al. (1986) suggested that increases in arousal were associated with increases in muscle activity levels. This evidence reveals that an increase in physiological arousal can directly modify postural control.

A threat to posture may produce system-wide changes with the convergence of physiological and psychological factors leading to a loss of confidence in one's ability to perform the balance task. A reduced balance efficacy could result in the individual not performing the task and restricting their activities. However, if the decision is made to perform the task, the individual may select an alternate strategy for postural control that may or may not be effective, placing the individual at a greater risk for falling. Further, low balance efficacy could directly influence the appraisal of the threat and its consequences the next time that the threat is encountered. Previous experience with a task can alter level of balance efficacy (Maddux 1995). Many older adults are quite capable physically of performing specific activities that challenge their balance; however, they may feel that they are unable to perform the activity due to the negative consequences or costs associated with any failure. Thus, success on the task may influence balance efficacy and the appraisal of the threat the next time that the threat is encountered. This has potential interesting application for treatment of fear of falling (Baumann 1999; King and Tinetti 1995; Tinetti et al. 1990, 1994; Tinetti and Powell 1993).

The complex interactions between the different elements of the model highlight the difficulty in identifying relationships between psychological and physiological measures and the resultant behaviour. The concept of triadic reciprocal causation is a critical assumption of social-cognitive theory. This concept describes cognition, behaviour and environmental events as mutually interacting factors; however, all three factors are not always influencing the other factor equally or at the same time (Bandura 1997; Maddux 1995). This concept can be applied to the balance efficacy postural control model presented in Figure 1.1. Thus, to understand a behavioural outcome, such as an increased risk of falling, it is critical to examine the contribution of all three factors.

Manipulation of postural threat to examine fear of falling in healthy young adults

Research examining the relationship between fear of falling or low balance confidence and the control of posture in the elderly and individuals with balance disorders is limited and remains poorly understood. The studies that have been conducted suggest that fear of falling does have observable effects on postural control, especially for more challenging or difficult postural tasks. However, it is difficult to distinguish psychological and physiological influences on postural control in the elderly and individuals with balance disorders as fear of falling may compound an already existing physiological deficit. An alternative approach is to examine the effects of fear or low balance confidence on postural control in healthy young adults, without confounds of age or disease. Many people experience fear or anxiety when standing at or approaching the top of a flight of stairs, the edge of a roof of a tall building or the edge of a cliff. Murphy and Issacs (1982) describing the cautious reactions observed in older adults with a fear of falling viewed this behaviour as similar to that experienced by normal individuals in a threatening environment such as walking on ice or standing at the edge of a precipice. When faced with a situation, in which the consequences of a fall are great, people may lose confidence in their balance abilities and the ability to control or cope with the situation in which they are placed. These changes may dramatically alter the strategies for the control of posture. The challenge is to present healthy young adults with a situation that can influence balance efficacy and induce an anxiety or fear response. Thus, the manipulation of surface height may provide insight into balance efficacy effects on postural control by altering the threat or risk of injury associated with the task. In particular, it provides an opportunity to observe in healthy young adults the experience of individuals who live with low balance efficacy or fear of falling (Brown and Frank 1997).

The manipulation of the surface height at which individuals stand has been used previously to probe the influence of postural threat or balance confidence on the control of posture during quiet stance (Carpenter et al. 1999, 2001) and the postural recovery strategy used to maintain upright stance following an external perturbation (Brown and Frank 1997). In these studies, the control of posture was examined in a non-threatening situation (standing at ground level) and in a threatening situation (standing on a platform 0.81 m above ground level). Carpenter et al. (1999) showed that the mean position of the COP was moved back away from the direction of the imposed threat and amplitude of COP displacement decreased while frequency increased in the anterior-posterior direction when standing on an elevated surface. Reduced amplitude and increased frequency of COP changes reflected an increased postural stiffness (Carpenter et al. 2001). Brown and Frank (1997) provided evidence that increased postural stiffness can serve as a strategy for limiting displacement of the centre of mass (COM) following destabilization by an external perturbation (push applied to the upper back) when standing at the edge of an elevated surface. Healthy young adults shifted the mean position of the COM back away from the edge of the platform prior to the perturbation and decreased the range of COM displacement and time to peak COM velocity in response to the perturbation. These findings suggest increased stiffness may serve to limit the displacement of the COM if an unexpected perturbation occurs, essentially providing an immediate response (Rietdyk et al. 1999; Winter et al. 1998). The work of Carpenter et al. (1999, 2001) and Brown and Frank (1997) suggests that the examination of postural threat effects on postural control in healthy young adults may contribute to the identification of physiological and psychological alterations in postural control in the elderly and individuals with balance disorders.

THESIS OBJECTIVES

The collective goal of the thesis was to investigate the effects of balance confidence on strategies for the control of posture. Current theory suggests that psychological factors influence the control of posture, however research in this particular area is limited. Understanding psychological influences on the control of posture will provide direction for clinical assessment and successful treatment intervention for elderly or individuals with balance disorders who are fearful of falling.

A series of three studies was conducted to explore the nature of the relationship between balance confidence and postural control. The first two studies investigated balance confidence as a psychological modulator of postural control in healthy young adults. Balance confidence was modified through the introduction of a threat to posture; postural threat was modified by requiring individuals to perform the postural task while standing at different surface heights above ground level. Although research has investigated alterations in postural control under different behavioural and environmental constraints (Horak and Macpherson 1996; Massion 1992), little is known concerning the effects of balance confidence on postural control. It was hypothesized that the threat to posture would initiate system-wide changes, including alterations in postural control, to promote the adoption of a more cautious strategy to minimize the potential disturbance of the COM. Two different postural tasks were explored including the control of posture during quiet stance and the co-ordination of postural adjustments and movement during a voluntary rise to toes task; each task provided a different challenge to the postural control system to determine if balance confidence effects were task-dependent. For example, an individual may not be threatened and feel highly confident in their ability to stand at a particular surface height but threatened and less confident in their ability to rise to the toes at that same height. Furthermore, an attempt was made to determine if postural responses were adjusted precisely to the level or intensity of the postural threat or influenced by the order in which the postural threat was presented by providing progressive increases or decreases in the level of postural threat. In the third study of the thesis, fear of falling or balance confidence and its relationship to the control of posture was examined in a clinical population: individuals diagnosed with PD. The prevalence of fear of falling or low balance confidence was first identified in this population and then a series of balance tests were administered to determine if fear of falling was related to balance performance. In this study, postural threat was manipulated by altering the difficulty or challenge associated with the stance task by limiting vision, narrowing the base of support, altering proprioceptive information or being possibly pushed or pulled off balance. It was hypothesized that fear of falling would be more prevalent in individuals with PD due to their well-documented impairments of balance and gait (Rogers et al. 1996). The results obtained from each investigation provide converging evidence identifying balance confidence as a key psychological modulator of postural control.

Throughout the thesis, different terms, such as fear, anxiety, confidence and efficacy were used to describe the response to an increase in postural threat. The selection and application of the different terms throughout the thesis was dictated first by the measures collected for each of the three studies and second by the target audience to whom the different chapters of the thesis were directed. The presentation of the model in Figure 1.1 was an attempt to reduce possible confusion regarding these terms and explain the complex interactions between the different levels of behaviour. It is hypothesized that balance efficacy influences the appraisal of postural threat, the psychological and physiological responses to this threat, and the behavioural outcome: strategies for the control of posture.

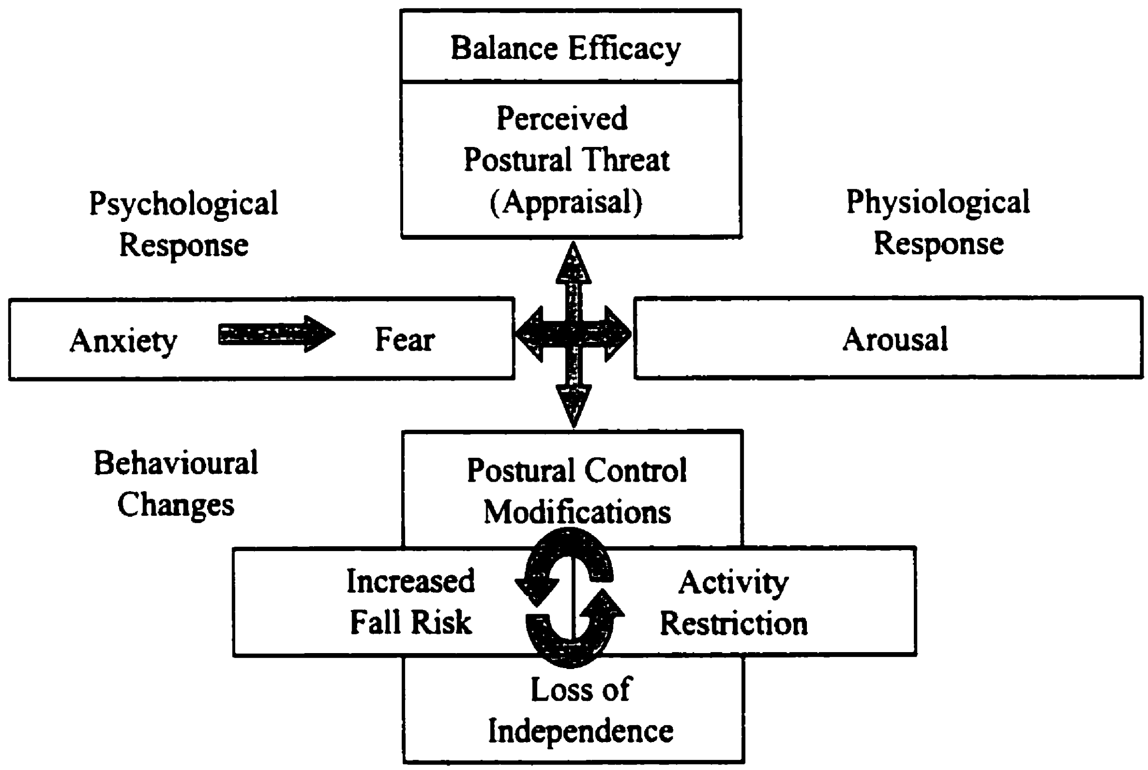

Figure 1.1. Proposed balance efficacy postural control model to illustrate the effects of balance efficacy on postural threat appraisal and the associated behavioural modifications that result from this interaction.

CHAPTER 2

POSTURAL CONTROL IS SCALED TO LEVEL OF POSTURAL THREAT

Allan L. Adkin, James S. Frank, Mark G. Carpenter, Gerhard W. Peysar

ABSTRACT

This study investigated control of posture when standing at different surface heights above ground level. Alterations in surface height were used to modify threat to postural control. Sixty-two healthy adults (mean ± SD = 20.3 ± 1.3 years) stood quietly on a force plate 0.4 m (LOW threat), 1.0 m (MEDIUM threat) or 1.6 m (HIGH threat) above ground level. Each standing trial was performed with eyes open for 120 s. Postural threat was presented in ascending (n=31) or descending (n=31) order with the first threat condition in each series (LOW threat for ascending group, HIGH threat for descending group) repeated. This manipulation allowed for an examination of set effects (i.e., prior experience of postural threat) on postural control. The results demonstrated scaling of postural control variables to level of postural threat. Amplitude of centre of pressure (COP) displacement decreased and frequency of COP displacement increased linearly as postural threat increased from LOW to HIGH. The central nervous system progressively tightened control of posture as postural threat increased. Initial exposure to the HIGH or LOW threat condition influenced postural control differently. The group who received the HIGH threat condition first (descending) demonstrated increased amplitude of COP displacement in the anterior-posterior direction compared to the group who received the LOW threat condition first (ascending). A "first trial" effect was observed when standing for two consecutive trials but only at the LOW threat condition. Decreased amplitude and increased frequency of COP displacement were observed on the first trial compared to the second trial. The results of this study demonstrated that control of posture is influenced not only by the threat to posture but also by the order in which the threat to posture is experienced.

INTRODUCTION

It is well documented that falls most often result from an interaction of multiple factors including age-related changes to the postural control system (Downton 1996). Psychological factors, such as fear of falling, may also constrain control of posture leading to falls (Alexander, 1994). Although elderly (Arfken et al. 1994; Downton and Andrews 1990; Murphy and Issacs 1982; Tinetti et al. 1988, 1994; Vellas et al. 1997; Walker and Howland 1991) and patients with balance disorders (Burker et al. 1995; Yardley and Hallam 1996) frequently report fear of falling, few studies have directly examined the relationship between this fear and postural control.

Maki et al. (1991, 1994) observed an association between fear of falling and control of posture. For example, elderly who reported a fear of falling demonstrated larger amplitude of postural sway when blindfolded and poorer scores when timed on a one-leg stance test compared to those who did not report a fear of falling. Krafczyk et al. (1999) have shown that patients with phobic postural vertigo adopt a tighter control of posture characterized by smaller amplitude and higher frequency postural sway compared to normals. The results of these two studies illustrate the possible confounding effects of fear of falling on postural control. However, it is difficult to distinguish psychological and physiological influences on postural control in elderly and patients with balance disorders as fear of falling may compound an already existing physiological problem (Yardley and Hallam 1996). To address this issue, Carpenter et al. (1999) and Brown and Frank (1997) examined postural control of healthy young adults when faced with a threat to their posture. These authors argued that fear of falling, based on perceived risk of injury as a result of instability, would be greater when standing on a high (0.81 m above ground level) compared to low platform height (0.19 m above ground level). Carpenter et al. (1999) showed that participants adopted smaller amplitude and higher frequency postural sway and leaned back away from the platform edge when standing on a high platform. Brown and Frank (1997) demonstrated that participants limited displacement and velocity of center of mass (COM) movement in response to a destabilizing push applied to the upper back when standing at the edge of a high platform. These findings suggest that in fearful situations the central nervous system (CNS) controls posture to limit the chances of the COM moving outside the base of support.

The results of these four studies provide evidence that fear of falling has observable effects on postural control. However, each of the studies discussed examined a dichotomous fearful versus non-fearful situation. An issue still unresolved is whether modifications to postural control vary with intensity of fear of falling or threat to posture. To investigate this question, we extended the work of Carpenter et al. (1999) and examined changes to control of posture when individuals stood under multiple levels of postural threat. In particular, we were interested in whether or not modifications to postural control were scaled to level of postural threat.

Previous research has shown that prior experience and expectation of an external perturbation can influence control of posture (e.g., Horak and Nashner 1986; Horak et al. 1989; Maki and Whitelaw 1993). Thus, a second question we examined focused on the postural response to a specific level of threat and whether or not this response was influenced by prior experience in a more or less threatening condition. To investigate this question, we altered presentation order of postural threat to determine whether the influence of threat is larger or smaller when preceded by a more threatening condition compared to a less threatening condition. We were also interested in whether postural control was influenced when standing at a particular level of postural threat if prior experience at that same level of threat was available and whether or not this effect was observed in both more or less threatening conditions. Two consecutive trials of both the least threatening condition and the most threatening condition were performed to examine this issue of "first trial" effects.

METHODS

Participants

Sixty-two healthy young adults (mean ± SD age = 20.3 ± 1.3 years) volunteered for this study. Each participant completed a medical history and physical activity questionnaire. Participants were free from any neurological or musculoskeletal disorder. Each participant, informed of the experimental procedures, provided written consent prior to the testing session. All experimental procedures were approved by the University of Waterloo Office of Research Ethics.

Experimental Protocol

Manipulation of Postural Threat

Postural threat was modified through alterations to the surface height at which individuals stood. Participants stood at three different surface heights above ground level. Surface height was altered using a hydraulic platform lift (Figure 2.1). A portable AMTI force plate, mounted on a planed marble base, was placed on the platform lift. The force plate was located 0.5 m from the front edge, 1.2 m from the back edge, and 0.35 m from both the left and right edges of the platform lift. A wooden surround was positioned on the platform lift around all four sides of the force plate. The surround extended out to the edges of the platform lift and was used to provide a level surface with the top of the force plate. The force plate was located 0.5 m from the anterior edge of the platform lift so as not to limit strategies for postural recovery. This distance was selected to afford selection of a stepping response as participant's could take one full step to recover posture if necessary (McIlroy and Maki 1993). The platform lift allowed the force plate to be raised to different heights above ground level. The distance from the top of the force plate to ground level was 0.4 m when the platform lift was completely lowered. The LOW threat condition was experienced when the platform lift was in this position. The platform lift was raised 1.0 m above ground level for the MEDIUM threat condition and 1.6 m above ground level for the HIGH threat condition.

Presentation Order of Postural Threat

Postural threat was presented in ascending (LOW to HIGH) or descending (HIGH to LOW) order. Thirty-one participants (mean ± SD age = 20.1 ± 1.1 years) were assigned to the ascending order group and thirty-one participants (mean ± SD age = 20.5 ± 1.5 years) were assigned to the descending order group. The initial standing trial for each group (LOW threat for the ascending order group, HIGH threat for the descending order group) was repeated to investigate "first trial" effects. The following series of standing trials were performed: LOW, LOW, MEDIUM, and HIGH threat for the ascending order group and HIGH, HIGH, MEDIUM, and LOW threat for the descending order group.

Procedure

Participants were instructed to stand quietly on the force plate with their arms at their sides and their eyes open. Participants fixated on a target located 6 m in front of them at eye level. The toes were placed at the anterior edge of the force plate and stance width was defined by the participant's foot length. Foot position was traced to maintain the same stance position for each trial. The duration of each standing trial was 120 s. At the completion of each trial, participants were seated and the platform was raised or lowered in preparation for the next standing trial. A 120 s rest period was provided between standing trials to minimize fatigue effects. Ground reaction force and moment of force signals were collected from the force plate with a sampling frequency of 20 Hz for the duration of each trial. Leg length, foot length and heel to ankle length of each participant were measured.

Data Reduction and Statistical Analysis

Centre of pressure (COP) was calculated in both the anterior-posterior (A-P) and medial-lateral (M-L) direction for each 120 s record. Summary measures used to quantify postural control were: mean position, standard deviation (SD), and mean power frequency (MPF) of the COP signal in both A-P and M-L directions. Mean position represented the average position of the COP over the 120 s record and was referenced in the A-P direction to the position of the ankle joint as calculated from foot length and heel to ankle length anthropometric measurements. Following removal of the mean position value, the COP signal was filtered with a dual pass Butterworth filter with a 5 Hz cutoff frequency. The SD of the COP signal was calculated to provide a measure of amplitude variability. A fast Fourier transformation of the COP signal followed by a MPF analysis was completed to provide an estimate of the average frequency contained within the power spectrum.

A logarithmic transformation was applied to COP summary measures to meet normal distribution requirements for statistical analyses. A two-way between and within subjects repeated measures analysis of variance procedure was performed for each dependent measure. Presentation order of postural threat (ascending or descending) and postural threat (LOW, MEDIUM, or HIGH) were the two factors investigated. For each significant postural threat effect observed, trend analysis was used to examine the shape of the function (i.e., linear or quadratic) relating postural threat and the postural control measure. The initial standing trials at the LOW threat condition for the ascending order group and at the HIGH threat condition for the descending order group were not included in this analysis. For each group, these trials were examined separately and compared only to the second standing trial completed for the same postural threat level using a one-way within subjects repeated measures analysis of variance procedure, with trial (first or second) as the single factor. This analysis allowed for an investigation of "first trial" effects. In all cases, a p value of less than 0.05 was used to indicate statistical significance.

RESULTS

Postural Threat Effects

Significant modifications to COP control in both A-P and M-L directions were observed as postural threat was increased from LOW to HIGH.

A-P SD showed a significant main effect of postural threat (F (2,119) = 7.85, p = 0.0006). As threat increased, A-P SD values linearly decreased (p = 0.0002) (Figure 2.2). The percent change decrease in mean A-P SD values from the LOW threat condition was 8.3 % for the MEDIUM and 15.7 % for the HIGH threat condition.

A-P MPF showed a significant main effect of postural threat (F (2,119) = 5.13, p = 0.007). As threat increased, A-P MPF values linearly increased (p = 0.001) (Figure 2.2). The percent change increase in mean A-P MPF values from the LOW threat condition was 8.4 % for the MEDIUM and 21.0 % for the HIGH threat condition.

A-P mean position also showed a significant main effect of postural threat (F (2,119) = 5.26, p = 0.007). A non-linear relationship for postural threat and A-P mean position was observed (p = 0.05). The A-P mean position was moved further away from the edge of the platform for the HIGH threat condition (mean ± SE = 3.79 ± 0.19 cm) compared to the MEDIUM (mean ± SE = 4.01 ± 0.20 cm) and LOW (mean ± SE = 3.96 ± 0.19 cm) threat conditions. The percent change increase in mean A-P mean position values for the HIGH threat condition was 4.3 % compared to the LOW threat and 5.5 % compared to the MEDIUM threat condition.

M-L SD showed a significant main effect of postural threat (F (2,119) = 6.01, p = 0.003). As threat increased, M-L SD values linearly decreased (p = 0.006) (Figure 2.3). The percent change decrease in mean M-L SD values from the LOW threat condition was 7.9 % for the MEDIUM threat and 9.0 % for the HIGH threat condition. Although not statistically significant (p=0.12), M-L MPF values tended to increase linearly as postural threat increased from LOW to HIGH.

Postural Threat Presentation Order Effects

A-P SD showed a significant main effect for presentation order of postural threat (F (1,60) = 4.32, p = 0.04). Higher A-P SD values were observed for the descending order group (mean ± SE = 0.503 ± 0.018 cm) compared to the ascending order group (mean ±

SE = 0.435 ± 0.016 cm) across all levels of postural threat. The difference in A-P SD values between the descending and ascending order groups represented a 16.3 % change. Figure 2.4 displays A-P SD values for both ascending and descending groups for each level of postural threat.

A significant main effect of postural threat presentation order was not observed for any other COP summary measure. Also, no significant interaction effect of postural threat by postural threat presentation order was detected.

First Trial Effects

Significant modifications to postural control were observed only between the first and second standing trial at the LOW threat condition for the ascending group. No significant differences were observed for any COP summary measure between the first and second standing trial at the HIGH threat condition for the descending group (Table 2.1).

A-P SD showed a trend for lower values on the first trial compared to the second trial at the LOW threat condition ($F(1, 30) = 3.63$, $p = 0.07$). The difference in A-P SD mean values between the first and second trial represented an 11.1 % change. A-P MPF values were significantly higher for the first trial compared to the second trial at the LOW threat condition ($F(1, 30) = 9.42$, $p = 0.005$). The difference in A-P MPF mean values between the first and second trial represented a 16.8 % change.

M-L SD values were lower for the first trial compared to the second trial at the LOW threat condition ($F(1, 30) = 9.22$, $p = 0.005$). The difference in M-L SD mean values between the first and second trial represented a 15.6 % change. M-L MPF values were significantly higher for the first trial compared to the second trial at the LOW threat condition ($F(1, 30) = 9.28$, $p = 0.005$). The difference in M-L MPF mean values between the first and second trial represented a 22.5 % change.

DISCUSSION

Postural control is scaled to level of postural threat

The results of this study show that the CNS precisely adjusts control of posture in response to different levels of postural threat. Amplitude of COP displacement decreased linearly and frequency of COP displacement increased linearly as postural threat increased from LOW to HIGH (Figure 2.2 and 2.3). The finding that postural control is scaled to level of postural threat extends the work of Carpenter et al. (1999) who observed similar changes in postural control but only between two levels of postural threat. The observation of a scaled change of strategy in response to increasing levels of postural threat could be attributed to a number of factors, for example, an increase in perceived risk of injury from falling and/or increased arousal.

Progressive increases in postural threat may be accompanied by progressive increases in perceived risk of injury from falling (Brown and Frank 1997; Carpenter et al. 1999). One of the primary goals of the CNS during standing is to control movement of the COM within the base of support. If the body is modeled as an inverted pendulum, COP adjustments can provide insight into how the CNS is controlling COM movement (Winter et al. 1990). In particular, changes in COP displacement will reflect changes in COM displacement as the difference between the COP and COM is highly correlated with horizontal accelerations of the COM (Winter et al. 1998). Thus, the COM can be regulated within a smaller boundary by reducing the amplitude and increasing the frequency of COP displacements. An increase in perceived risk of injury from falling may contribute to a tighter control of posture to decrease the possibility of the COM falling outside of the base of support. A similar strategy was observed for patients with postural phobic vertigo (Krafczyk et al. 1999). Maki and colleagues (1991) have suggested compensations including reduced COP movements were adopted during M-L eyes-open induced-sway tests when apprehensive individuals perceive their balance to be compromised. Thus, the provision of a greater margin of safety by controlling the COM within a smaller area may aid in recovering postural stability following an external perturbation (Brown and Frank 1997; Winter et al. 1998).

Progressive increases in postural threat might also be accompanied by progressive increases in arousal. Fridlund et al. (1986) suggested that increases in arousal were associated with increases in muscle activity levels. Maki and McIlroy (1996) showed that when healthy young subjects attended to a cognitive task, arousal was increased and changes in postural control including increased tibialis anterior muscle activation and forward leaning were observed. Increased arousal levels may contribute to the lower amplitude, higher frequency postural sway observed when standing under conditions associated with an increased threat to posture.

Prior experience of postural threat influences postural control

The results of this study show that prior experience or initial exposure to a HIGH or LOW threat influenced postural control. The same graded patterns of decreased amplitude and increased frequency of COP displacement in response to increasing levels of postural threat were observed for both ascending and descending order groups. However, the group who received the HIGH threat condition first (descending group) demonstrated greater amplitude of COP displacement in the A-P direction across all levels of postural threat compared to the group who received the LOW threat condition first (ascending group).

The influence of prior experience of postural threat on control of posture is most evident when examining the response for the MEDUIM threat condition in Figure 2.4. The MEDIUM threat condition may actually present a different level of postural threat to each group. For example, the MEDIUM threat condition for the descending group would be considered less threatening compared to their previous experience at the HIGH threat condition. In contrast, the MEDIUM threat condition for the ascending group would be considered more threatening compared to their previous experience at the LOW threat condition. Furthermore, as the ascending group has yet to experience the most threatening condition, overall tighter control over posture may persist. The difference in amplitude of A-P COP displacement (25 % higher for the descending group) between the two groups for this MEDIUM threat condition provides insight into the effects of postural set (i.e., prior experience) on control of posture. These findings are in accordance with our observations of tighter control of posture under more threatening conditions.

First Trial Effects

We observed a "first trial" effect when standing for two consecutive trials in the LOW postural threat condition (Table 2.1). A tighter control of posture was observed when experiencing the LOW threat condition for the first time. The experience of the first trial may be considered more threatening to participants due to uncertainty associated with this initial exposure as none of the participants had previously participated in an experiment of this nature. Increased amplitude and decreased frequency of COP displacement observed for the second trial may result from the condition being viewed as less threatening compared to the first trial due to familiarity with the experimental procedure or experience gained from successful performance of the first trial. The difference in postural control between the first and second trials may result from changes in arousal levels. Maki and Whitelaw (1993) have shown a decrease in arousal levels with repeated testing. We did not observe a "first trial" effect on postural control when standing for two consecutive trials in the HIGH threat condition. Absence of a "first trial" effect when beginning at the HIGH threat condition may be masked as this condition was viewed as threatening regardless of whether or not the trial was performed first or second. These findings provide further evidence of tighter control of posture under more threatening conditions.

CONCLUSIONS

The observations for healthy young adults suggest the CNS adopted tighter control of posture under conditions of increased postural threat and that this control was precisely scaled to the level of postural threat. The control of posture was also influenced by the order in which the threat to posture was experienced.

These results emphasize the importance of identifying both psychological and physiological influences on postural control when assessing individuals with balance disorders or managing elderly individuals at risk for falls. Although balance problems may result from an underlying physiological cause, psychological factors, such as fear of falling, may compound the problem. As fear of falling is frequently reported in the elderly and patients with balance disorders, our understanding of how psychological factors modify postural control is critical for designing successful treatment interventions.

Table 2.1. Mean and standard error values for A-P and M-L standard deviation (SD) and mean power frequency (MPF) for the first and second trial performed at the LOW threat condition for the ascending order group and at the HIGH threat condition for the descending order group.

	Ascending (LOW THREAT)			Descending (HIGH THREAT)		
	Trial 1	*Trial 2*	*p value*	*Trial 1*	*Trial 2*	*p value*
A-P SD (cm)	0.425 (0.023)	0.478 (0.030)	0.0664	0.456 (0.025)	0.448 (0.022)	0.7839
A-P MPF (Hz)	0.153 (0.010)	0.131 (0.015)	0.0045*	0.129 (0.009)	0.135 (0.010)	0.5756
M-L SD (cm)	0.292 (0.015)	0.346 (0.022)	0.0049*	0.321 (0.019)	0.336 (0.021)	0.4051
M-L MPF (Hz)	0.228 (0.013)	0.187 (0.016)	0.0048*	0.198 (0.014)	0.199 (0.017)	0.9682

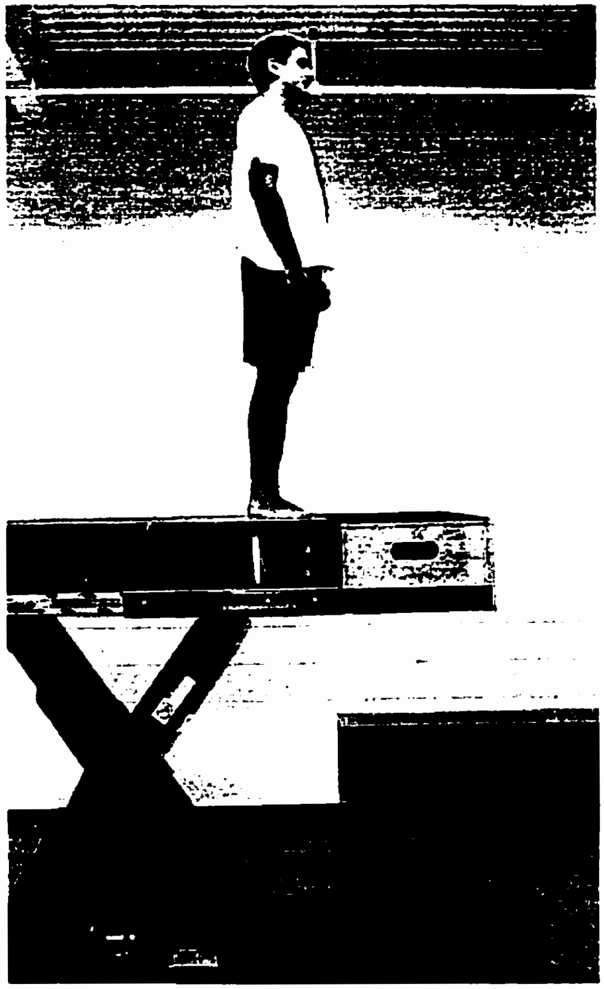

Figure 2.1. View of the hydraulic platform lift used to manipulate surface height. Surface height was set at 0.4 m (LOW Threat), 1.0 m (MEDIUM Threat) or 1.6 m (HIGH Threat) above ground level. The present view shows a participant standing on the force plate one full step from the edge (0.5 m) at the HIGH threat condition.

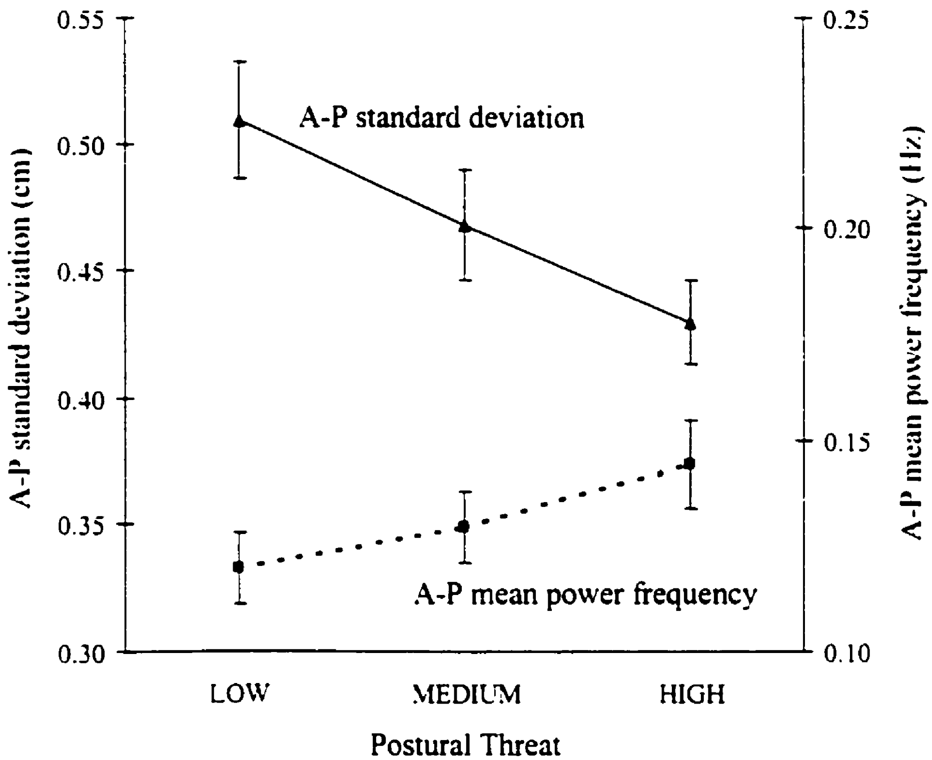

Figure 2.2. Mean A-P SD (solid line) and A-P MPF (dashed line) for LOW, MEDIUM, and HIGH threat conditions. Amplitude decreased while frequency increased linearly as postural threat increased. Error bars represent ± 1 standard error.

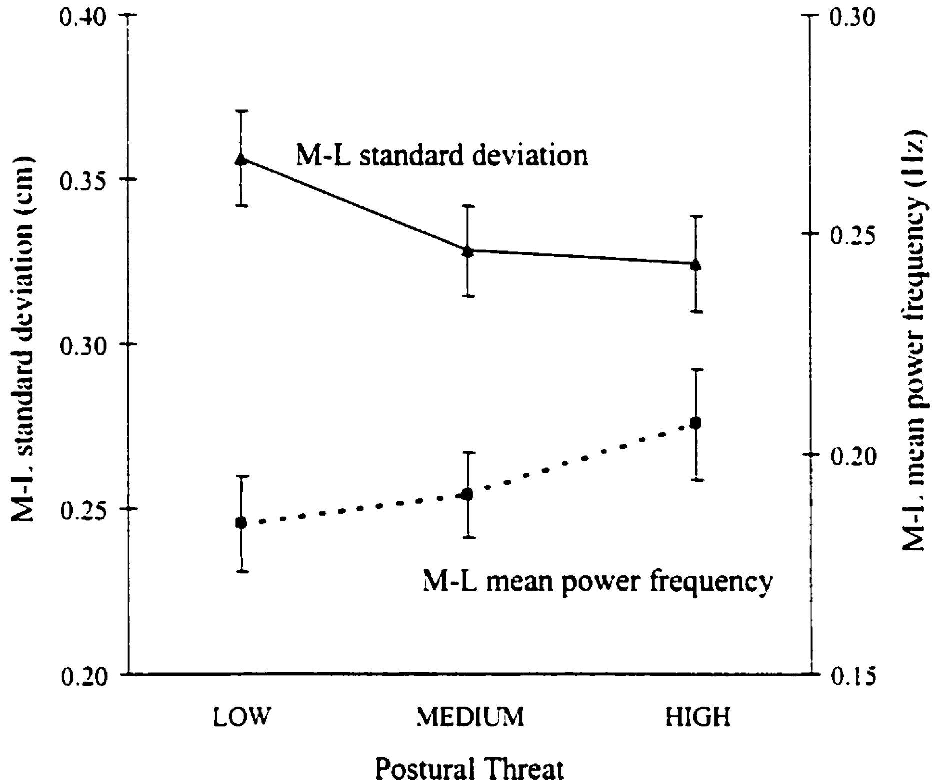

Figure 2.3. Mean M-L SD (solid line) and M-L MPF (dashed line) for LOW, MEDIUM, and HIGH postural threat. Amplitude decreased while frequency increased progressively as postural threat increased. Error bars represent ± 1 standard error.

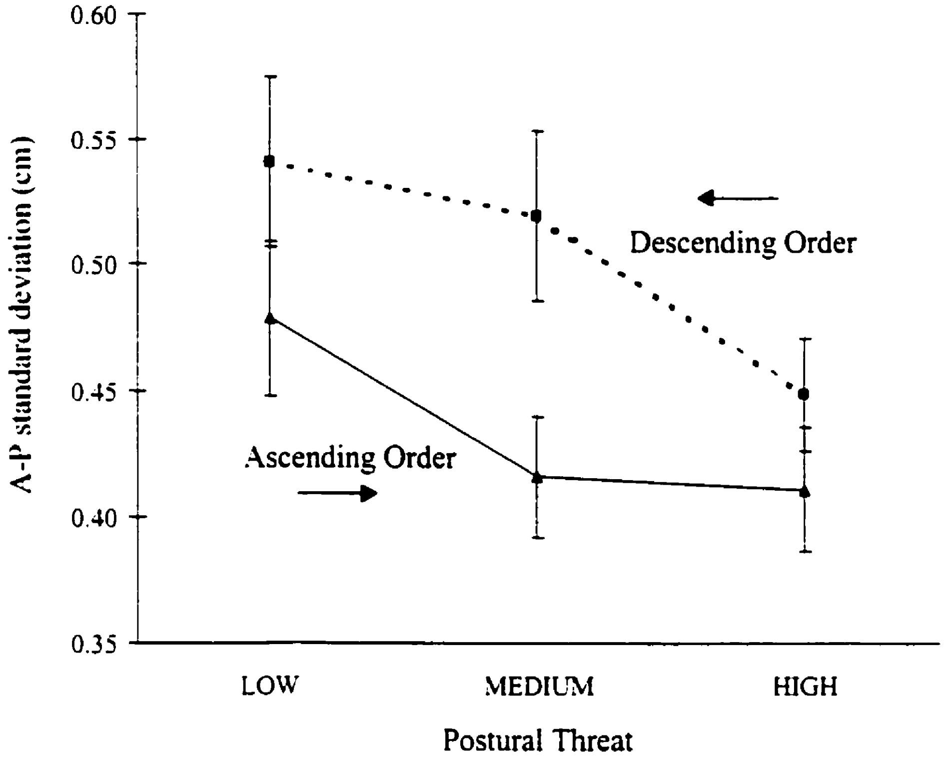

Figure 2.4. Mean A-P SD for ascending (solid line) and descending (dashed line) presentation order groups for LOW, MEDIUM, and HIGH threat conditions. Note that the MEDIUM threat condition is more threatening for the ascending order group but less threatening for the descending order group. Error bars represent ± 1 standard error. A postural threat by presentation order of postural threat interaction was not observed; there was a significant main effect of postural threat and presentation order of postural threat.

CHAPTER 3

POSTURAL THREAT MODIFIES ANTICIPATORY POSTURAL CONTROL

Allan L. Adkin, James S. Frank, Mark G. Carpenter, Gerhard W. Peysar

ABSTRACT

This study investigated the influence of fear of falling or postural threat on the control of posture and movement during a voluntary rise to toes task for twelve healthy young adults. Postural threat was modified through alterations to the surface height at which individuals stood (low or high platform) and changes in step restriction (away from or at the edge of the platform) creating four levels of increasing postural threat: LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE. To rise to the toes, an initial postural adjustment must destabilize the body so that it can be moved forward and elevated to a new position of support over the toes. Centre of pressure and centre of mass profiles, as well as tibialis anterior (TA), soleus (SO) and gastrocnemius (GA) muscle activity patterns were used to describe this behaviour. The results showed that the performance of the rise to toes task was modified in response to increasing levels of postural threat. The central nervous system progressively reduced the magnitude and rate of the postural adjustment and subsequent voluntary movement as level of postural threat increased; the most prominent alterations in control were observed for the most threatening condition, rising to the toes at the edge of a high platform. Although the duration of the movement was lengthened for this most extreme condition, the sequencing and relative timing of TA, SO and GA muscle activity was preserved across level of postural threat. These changes in rise to toes behaviour were accompanied by evidence of increased physiological arousal and participant reports of decreased confidence, increased anxiety and decreased stability. The results of this study demonstrate that fear influences anticipatory postural control; these observations have clinical relevance for individuals with balance disorders with a fear of falling. For example, individuals with Parkinson's disease or cerebellar dysfunction demonstrate impaired performance on the rise to toes

task as reflected in alterations of both the timing and magnitude of their anticipatory postural adjustments. Our findings suggest that fear of falling may influence rise to toes behaviour in these populations; alterations in the magnitude of postural adjustments may be magnified by fear while changes in the timing of postural adjustments may reflect underlying pathology.

INTRODUCTION

It is well known that the central nervous system (CNS) preserves stability of the body by generating postural adjustments simultaneously with or just prior to the initiation of voluntary movement (Massion 1992). The magnitude and timing of these postural adjustments is critical and depends on the physical demands associated with the movement as well as the behavioural context in which the movement is performed (e.g., Aruin et al. 1998; Brown and Frank 1987; Cordo and Nashner 1982; Horak et al. 1984; Lee et al. 1987; Nardone and Schieppati 1988; Toussaint et al. 1998). An anticipatory postural adjustment (APA) may serve to counteract the destabilizing forces that result from the movement acting to stabilize the body centre of mass (COM). Alternatively, an APA may serve to assist movement initiation by destabilizing the body in the direction of the intended movement.

In the case of rising to the toes, an APA destabilizes the body COM so that it can be moved forward and elevated to a new position of support over the toes. The APA, accomplished through activation of the tibialis anterior (TA) and/or silencing of the soleus (SO) or gastrocnemius (GA), causes the centre of pressure (COP) to move backward and body COM to move forward. Subsequent activation of the SO and GA arrests the forward movement of the COM moving the body up and over the new base of support on the toes (Clement et al. 1984; Diener et al. 1990; Kasai and Kawai 1994; Lipshits et al. 1981; Nardone and Schieppati 1988). The movement up and onto the toes is compromised if this initial postural adjustment is absent, of insufficient magnitude or inappropriately timed. For example, individuals with Parkinson's disease (PD) or cerebellar dysfunction demonstrate impaired performance on the rise to toes task as reflected in alterations of the magnitude and timing of their postural adjustments (Diener et al. 1990, 1992; Frank et al. 2000; Kaneoke et al. 1989). These alterations in postural control are normally attributed to underlying physiological changes resulting directly from the disease process. However, psychological factors, such as fear of falling may act to compound the balance problem.

The need to understand fear of falling and its relationship to postural control has become apparent, as this fear is highly prevalent in the elderly (Arfken et al. 1994; Downton and Andrews 1990; Murphy and Isaacs 1982; Tinetti et al. 1988, 1994; Vellas et al. 1997; Walker and Howland 1991) and patients with balance disorders (Burker et al. 1995; Yardley and Hallam 1996). Maki et al. (1991, 1994) and Krafczyk et al. (1999) demonstrated the possible confounding effects of fear of falling on the control of posture in the elderly and patients with phobic postural vertigo, respectively. Lepicard et al. (2000), using an animal model, identified a relationship between anxiety and postural control as more anxious strains of mice demonstrated poorer balance performance compared to non-anxious strains of mice. Our research focuses on identifying the effects of fear of falling on strategies for postural control in healthy young adults to address whether changes displayed by the elderly or patients with balance disorders are of a physiological or psychological origin. In our previous studies (Adkin et al. 2000; Brown and Frank 1997; Carpenter et al. 1999, 2001), we introduced a threat to posture by having individuals stand at different surface heights above ground level. When standing at the edge of a high platform, the consequences of a fall are more severe and postural recovery options are reduced. For example, one would be unable to take a step to recover balance. This situation may provide a similar challenge to that experienced by an individual who has a fear of falling and reduced options for recovery due to physiological changes to the postural control system. These studies have demonstrated that a threat to posture does modify strategies for the control of posture. When threatened, participants adopted a tighter control of posture, characterized by smaller amplitude and higher frequency postural sway during quiet standing (Adkin et al. 2000; Carpenter et al. 1999, 2001) and reduced displacement and velocity of COM movement in response to a destabilizing push applied to the upper back (Brown and Frank 1997).

The purpose of this study was to examine the influence of fear of falling or postural threat on the organization of posture and voluntary movement during a rise to toes task in healthy young adults. In this study, fear of falling is considered low balance confidence in the ability to perform a specific activity as described by Tinetti et al. (1990) and Powell and Myers (1995). The influence of fear or postural threat effects on anticipatory postural control has not been investigated. However, previous research has shown that anticipatory postural control can be influenced by task demands including cognitive factors, such movement instructions (Horak et al. 1984; Lee et al. 1987; Nardone and Schieppati 1988) or movement predictability (Brown and Frank 1987; Toussaint et al. 1998). Thus, we hypothesized that when rising to the toes under a greater threat to posture, the timing and/or magnitude of the APA and voluntary movement may be altered.

An understanding of fear effects on anticipatory postural control is clinically relevant as it may help to explain deficits in this control observed in individuals with balance disorders. For example, the behaviour observed in healthy young adults when threatened may be similar to and/or different from that observed in individuals with balance problems such as PD or cerebellar dysfunction. The rise to toes patterns observed in individuals with balance problems that resemble the patterns observed in healthy young adults when threatened could implicate fear as a potential confound in this behaviour whereas patterns that are dissimilar could reflect the actual disease process. This comparison could address whether the changes displayed in rise to toes behaviour by individuals with balance problems are of a physiological or psychological origin.

METHODS

Participants

Twelve healthy young adults (6 females and 6 males, mean ± SD age = 26.5 ± 3.9 years) volunteered to participate in this study. Each participant completed a medical history and physical activity questionnaire. Exclusion criteria included any self-reported neurological, balance or musculoskeletal disorder. Each participant, informed of the experimental procedures, provided written consent prior to the testing session. The University of Waterloo Office of Research Ethics approved all experimental procedures.

Experimental Protocol

Manipulation of Postural Threat

Postural threat was modified through alterations to the surface height and step restriction of the support surface on which individuals stood. Surface height was altered using a hydraulic platform lift (width 1.2 m, length 2.2 m) which could be raised to different heights above ground level (Figure 3.1). A portable AMTI force plate, mounted on a planed marble base, was placed on the lift. The vertical distance from the top of the force plate to ground level was 0.4 m when the lift was completely lowered. The low surface height condition was experienced when the lift was in this position. For the high surface height condition, the lift was raised so that the vertical distance from the top of the force plate to ground level was 1.6 m. Step restriction was altered by having individuals stand with their toes at or away from the edge of the lift. For the latter condition, a wooden box (0.5 m deep) was securely mounted to the lift in front of the force plate and level with the force plate surface; this allowed one full step to recover balance if necessary (McIlroy and Maki 1993). The combination of changes in surface height and step restriction created four levels of postural threat: low surface height with no step restriction (LOW AWAY), low surface height with step restriction (LOW EDGE), high surface height with no step restriction (HIGH AWAY) and high surface height with step restriction (HIGH EDGE). Level of postural threat was presented in the same order for each participant: LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE. Postural threat was considered to increase from LOW AWAY to HIGH EDGE conditions. This order of presentation prevented a more threatening condition from influencing the performance on a less threatening condition; presentation order of postural threat has been shown to influence the control of posture (Adkin et al. 2000).

Procedure

Each participant, prior to the start of the experiment, performed twenty practice rise to toes trials at ground level to remove any potential learning effect. Participants were instructed to stand quietly on the force plate with their arms at their sides and their eyes open. Participants fixated on a target located 6 m in front of them at eye level. The toes were placed at the anterior edge of the force plate and maximum stance width was equal to the participant's foot length. Foot position was traced to maintain the same initial stance position for each trial. From this initial standing position, participants were instructed to voluntarily rise to the toes as quickly as possible following a verbal cue and maintain this new position of support over the toes for three seconds. Participants were instructed to perform the task using only their ankles and to avoid extensively flexing their knees or hips or moving their arms. Five consecutive rise to toes trials were completed for each level of postural threat. Unsuccessful rise to toes trials were repeated with the frequency of unsuccessful attempts recorded. At the completion of each block of rise to toes trials, participants were seated and provided with a rest period. Participants wore a safety harness, which was tethered to the ceiling, throughout the entire testing session. The harness did not provide support to the participant during the trials unless loss of balance occurred. Participants were not allowed to test the security of the harness.

Data Collection and Reduction

Physiological Arousal

Skin conductance measures provided an estimate of physiological arousal. Skin conductance was recorded using disposable surface electrodes placed on the thenar and hypothenar eminences (Skin Conductance Coupler, Coulbourn Instruments) based on the recommendations of Fowles et al. (1981). The skin conductance signal was collected with a sampling frequency of 1024 Hz; this raw signal was low-pass filtered at 5 Hz using a dual-pass second-order Butterworth filter. While seated at the low height, skin conductance was collected and this value reflected a baseline resting skin conductance level. For each rise to toes trial, skin conductance was averaged across the duration of the trial and expressed as a percent change from the skin conductance level observed at the initial seated condition.

Perceived Confidence, Anxiety and Stability

For each level of postural threat, perceived confidence, anxiety and stability measures were reported by the participant. Prior to the series of rise to toes trials, participants were asked to rate their confidence in their ability to maintain their balance and avoid a fall during the task. The rating scale ranged from 0 % (no confidence) to 100 % (complete confidence). Following each series of rise to toes trials, perceived anxiety and stability ratings were obtained. Perceived anxiety levels were assessed using a 16-item questionnaire (Refer to Appendix) modified from Smith et al. (1990). Participants scored each item on the questionnaire using a 9-point scale ranging from 1 (I did not feel this at all) to 9 (I felt this extremely). Items were classified into somatic (6 items), worry (4 items), and concentration (6 items) subgroups. All 16 items were summed to generate a total score for the questionnaire and items were also summed within each subgroup to examine the three different elements of the questionnaire. Postural stability ratings were obtained based on the example of Schieppati et al. (1999). Participants were asked to rate how stable they had felt during the series of rise to toes trials. The rating scale ranged from 0 % (I did not feel stable at all) to 100 % (I felt completely stable).

Centre of Pressure and Centre of Mass

Ground reaction force and moment of force signals were collected from the force plate with a sampling frequency of 1024 Hz to allow calculation of centre of pressure (COP). Participants were also instrumented with 21 infrared emitting diodes (IREDs) providing an estimation of total body centre of mass (COM) using the 14 segment model described by Winter et al. (1998). The IREDs were tracked with a collection frequency of 64 Hz using the OPTOTRAK motion analysis system (Northern Digital, Inc.). COP and COM profiles in the anterior-posterior (A-P) direction were examined for each trial. COP data was down-sampled to 64 Hz to temporally align the COP and COM trajectories. The COP and COM signals were low-pass filtered with a cut-off frequency set at 5 Hz using a dual-pass second-order Butterworth filter.

Key COP and COM summary measures were selected to describe the rise to toes behaviour (Figure 3.2). The time at which peak backward displacement of the COP trajectory occurred was selected as the temporal reference point for all measures (i.e., set to 0 ms). The A-P COP displacement profile was divided into APA and forward movement components. The COP APA component was defined as the interval from onset of change in displacement to peak backward displacement of the COP. The onset of change in COP displacement was determined by calculating a mean baseline value over 200 ms during the quiet interval before the rise to toes was initiated and searching for the point at which the profile moved above this baseline value plus two standard deviations and remained above this value for a 50 ms interval. The COP forward movement component was defined as the interval from peak backward to peak forward displacement of the COP. The magnitude and duration for the COP APA and forward movement components were determined. Furthermore, the COP displacement profile was differentiated to obtain a COP velocity profile; peak backward velocity for the COP APA component and peak forward velocity for the COP forward movement component were identified.

The A-P COM displacement profile was characterized by a single forward movement component. The COM forward movement component was defined as the interval from onset of change in displacement to peak forward displacement of the COM. The onset of change in COM displacement was determined with the same procedure used for COP. The magnitude and duration for the COM forward movement component were determined. The COM displacement profile was twice differentiated to obtain a COM acceleration profile; peak forward acceleration for the COM forward movement component was identified. Furthermore, the number of crossings of the COM trajectory by the COP was determined for the interval between the peak backward displacement of the COP to peak forward COM displacement to provide an estimate of stability associated with the movement.

Electromyography

Raw electromyographic (EMG) signals were collected with disposable surface electrodes placed bilaterally on the tibialis anterior (TA), soleus (SO) and medial gastrocnemius (GA) muscles. The EMG signals were collected with a sampling frequency of 1024 Hz. The raw EMG signals were rectified and low-pass filtered using a dual-pass second-order Butterworth filter. The cut-off frequency for the low-pass filter was set at 100 Hz. For each trial and muscle, muscle onset latencies were determined using the following procedure. First, a mean value was calculated over a 200 ms interval prior to any noticeable onset of muscle activity. This value, reflecting baseline or resting muscle activity level, was then subtracted from the signal. Second, a computer algorithm was utilized to select the onset of muscle activity according to several criteria. Onset of muscle activity was defined as the moment when EMG activity surpassed the established baseline muscle activity level plus two standard deviations and remained above this value for a 50 ms interval. The exact point of onset was determined by searching backward to the time at which the muscle activity moved above the baseline level. Verification of the onset latency selected by the computer algorithm was made visually; a manual selection occurred for less than 3.0 % of all selections. Following the determination of the muscle onset latency, integrated EMG activity levels were calculated over a 250 ms interval from the onset of the muscle activity. The algorithm also searched for offset of muscle activity to identify any silencing of the SO or GA muscle group using the same criteria except that the muscle offset was defined as the moment when EMG activity fell below the established baseline muscle activity level plus two standard deviations.

Statistical Analysis

A two-way repeated measures analysis of variance (ANOVA) procedure was performed for the skin conductance measure and each COP, COM and EMG measure. Level of postural threat (4 levels: LOW AWAY, LOW EDGE, HIGH AWAY, HIGH EDGE) and trial (5 levels: 1-5) were the two factors investigated. One-way repeated measures ANOVA procedures were performed for the perceived confidence, anxiety and stability measures. Level of postural threat (4 levels: LOW AWAY, LOW EDGE, HIGH AWAY, HIGH EDGE) was the factor investigated. These measures were specific to the series of rise to toes trials and thus a trial effect could not be examined. A p-value of less than 0.05 was used to indicate statistical significance for all cases. Bonferroni post-hoc comparisons were performed for any significant main effects of postural threat and trial to investigate differences between the four levels of postural threat and five levels of trial, respectively. If necessary, a logarithmic transformation was applied to dependent measures to meet normal distribution requirements for statistical analyses.

Chi-square analysis was performed to examine the frequency of unsuccessful rise to toes trials for both level of postural threat and level of trial. Correlations were performed between postural control measures, physiological arousal measures and perceived confidence, anxiety and stability measures.

RESULTS

Postural Threat Effects

Physiological Arousal and Perceived Confidence, Anxiety and Stability

A significant main effect of postural threat was observed for the percent change in physiological arousal from the initial seated condition ($F(3,33) = 16.16$, $p=0.0001$) and for self-reported levels of perceived confidence ($F(3,33) = 19.71$, $p=0.0001$), anxiety ($F(3,33) = 14.14$, $p=0.0001$) and stability ($F(3,33) = 17.72$, $p=0.0001$). Physiological arousal progressively increased (63.5 %) and participants reported being progressively less confident (46.0 %), more anxious (77.3 %) and felt less stable (44.0 %) as postural threat increased from LOW AWAY to HIGH EDGE (Figure 3.3). The HIGH EDGE condition was significantly different from the LOW AWAY, LOW EDGE and HIGH AWAY conditions.

When each subgroup of the perceived anxiety questionnaire was examined independently, somatic-related items ($F(3,33) = 13.11$, $p=0.0001$), worry-related items ($F(3,33) = 9.17$, $p=0.0001$) and concentration-related items ($F(3,33) = 7.82$, $p=0.0004$), also showed significant main effects of postural threat. The same trends observed for the full anxiety questionnaire were also observed for each of the three subgroups.

Centre of Pressure and Centre of Mass

COP and COM trajectories for the least threatening condition (LOW AWAY) and most threatening condition (HIGH EDGE) are presented in Figure 3.2. These profiles illustrate the significant differences in COP and COM control observed for the most threatening condition.

Initial Position

A significant main effect of postural threat was observed for the initial position of the COP ($F(3,33) = 6.54$, $p=0.0014$) and COM ($F(3,33) = 7.17$, $p=0.0008$). The initial position of both the COP and COM was moved backward, further away (~ 1.2 cm) from the edge of the platform for the HIGH EDGE condition when compared with LOW AWAY, LOW EDGE and HIGH AWAY conditions.

Anticipatory Postural Adjustment

A significant main effect of postural threat was observed for the magnitude ($F(3,33) = 29.65$, $p=0.0001$) and peak velocity ($F(3,33) = 28.61$, $p=0.0001$) of the COP APA. Both COP APA magnitude and peak velocity values decreased progressively as postural threat increased from LOW AWAY to HIGH EDGE (Figure 3.4a and b). The percent change decrease from LOW AWAY to HIGH EDGE was 63.5 % for COP APA magnitude and 58.5 % for COP APA peak velocity. For both measures, the HIGH EDGE condition was significantly different from the LOW AWAY, LOW EDGE and HIGH AWAY conditions. For COP APA peak velocity, a significant difference also was observed between the LOW AWAY and HIGH AWAY conditions. The duration of the COP APA remained unchanged across level of postural threat (Figure 3.4c).

Forward Movement

A significant main effect of postural threat was observed for the magnitude of the forward COP movement ($F(3,33) = 30.99$, $p=0.0001$) and peak velocity of forward COP movement ($F(3,33) = 34.73$, $p=0.0001$). Alterations in COM control accompanied these changes in COP control as a significant main effect of postural threat was observed for the magnitude of forward COM movement ($F(3,33) = 5.08$, $p=0.0053$) and peak acceleration of the forward COM movement ($F(3,33) = 30.92$, $p=0.0001$). The magnitude and peak velocity of the forward COP movement as well as the magnitude and peak acceleration of the forward COM movement decreased progressively as postural threat increased from LOW AWAY to HIGH EDGE (Figure 3.5a-d). The percent change decrease from LOW AWAY to HIGH EDGE was 24.5 % for magnitude and 60.3 % for peak velocity of forward COP movement and 8.8 % for magnitude and 56.2 % for peak acceleration of forward COM movement. For both the magnitude of forward COP and COM movement, the HIGH EDGE condition was significantly different from the LOW AWAY, LOW EDGE and HIGH AWAY conditions. For forward COP peak velocity and forward COM peak acceleration, a significant difference also was observed between the LOW AWAY and HIGH AWAY conditions.

A significant main effect of postural threat was observed for the duration of the forward COP movement ($F(3,33) = 12.27$, $p=0.0001$) and forward COM movement ($F(3,33) = 12.47$, $p=0.0001$). The duration of both the forward COP and COM movement was lengthened for the HIGH EDGE condition when compared to the three other levels of postural threat (Figure 3.5e and f). The percent change from LOW AWAY to HIGH

EDGE was 63.2 % for COP and 35.8 % for COM forward movement duration. Significant differences also were observed between the LOW AWAY and HIGH AWAY conditions for forward COP movement duration whereas no differences between the LOW AWAY, LOW EDGE and HIGH AWAY conditions were observed for forward COM movement duration.

Stability

A significant main effect of postural threat was revealed for the number of crossings of the COM by the COP over the interval from peak backward COP displacement to maximum displacement of the COM ($F(3,33) = 5.33$, $p=0.0042$). The number of crossings was significantly greater for the HIGH EDGE condition compared to the remaining three levels of postural threat (Figure 3.6). There were no differences in the number of crossings between the LOW AWAY, LOW EDGE and HIGH AWAY conditions.

Electromyography

Muscle onset latency and integrated muscle activity levels did not differ for right and left muscle pairs; therefore, these were averaged and examined together. The APA required to rise to the toes can be generated either by activating the TA muscle group or reducing or silencing the activity in the SO and/or GA muscle groups. For ten of the twelve participants, the APA involved activating the TA. For the remaining two participants, the APA involved first silencing the SO and/or GA muscles and then activating the TA. These two participants adopted this behaviour across all levels of postural threat. The EMG measures for these two participants were not included in the statistical analysis.

Muscle Activity Level

EMG profiles for the least threatening condition (LOW AWAY) and most threatening condition (HIGH EDGE) are presented in Figure 3.7. Background muscle activity levels, measured before any noticeable muscle onset, remained unchanged across all levels of postural threat. Integrated EMG activity levels, determined over a 250 ms interval after muscle onset, revealed significant main effects of postural threat for TA (F(3,27) = 6.94, p=0.0016), SO (F(3,27) = 11.07, p=0.0001) and GA (F(3,27) = 9.60, p=0.0002). Muscle activity levels were progressively reduced as postural threat increased from LOW AWAY to HIGH EDGE with the largest changes observed for the HIGH EDGE condition compared to the LOW AWAY condition (Figure 3.8). The percent change decrease from LOW AWAY to HIGH EDGE was 60.1 % for TA, 80.2 % for SO and 72.6 % for GA.

Muscle Onset Latency

The sequence of muscle activation was consistent for all trials; TA was activated first followed by SO and GA. Muscle onset latency showed a significant main effect of postural threat for TA (F(3,27) = 3.11, p=0.0450), SO (F(3,27) = 8.06, p=0.0008) and GA (F(3,27) = 4.01, p=0.0196). The onset of the TA, SO and GA activity was progressively delayed as postural threat increased from LOW AWAY to HIGH EDGE with the greatest delay observed for the HIGH EDGE condition compared to the LOW AWAY condition (Figure 3.9). However, the relative timing between TA and SO onsets (mean ± SE = 380 ± 6 ms) and TA and GA onsets (mean ± SE = 392 ± 7 ms) remained consistent across all levels of postural threat.

Unsuccessful Rise to Toes Attempts

The most threatening condition had significantly more unsuccessful rise to toes attempts compared to all other conditions ($\chi^2_{(3)}$ = 16.14, p=0.0001). An unsuccessful attempt occurred on 16.7 % of trials in the HIGH EDGE condition compared to 1.6 %, 3.3 % and 8.3 % in the LOW AWAY, LOW EDGE and HIGH AWAY conditions, respectively.

Trial Effects

No interaction effects were observed between trial and postural threat. A trial main effect was observed for the following measures: COP APA magnitude (F(4,44) = 3.78, p=0.0100) and peak velocity (F(4,44) = 3.45, p=0.0155), forward COP magnitude (F(4,44) = 3.86, p=0.0090), peak velocity (F(4,44) = 4.21, p=0.0057) and duration

(F(4,44) = 4.01, p=0.0074), forward COM peak acceleration (F(4,44) = 6.95, p=0.0002) and duration (F(4,44) = 5.15, p=0.0017), integrated muscle activity levels for TA (F(4,44) = 3.52, p=0.0172) and SO (F(4,44) = 3.08, p=0.0299). In summary, post-hoc comparisons revealed differences in the first trial compared to trials 2 through 5. Independent of level of postural threat, the first trial was characterized by reduced magnitude and velocity of the COP APA, reduced magnitude, velocity and increased duration of the forward COP movement and reduced acceleration and increased duration of the forward COM movement. Reduced muscle activity levels for TA and SO were also observed for the first trial. Furthermore, the first trial also was associated with more unsuccessful rise to toes attempts compared to all other trials ($\chi^2_{(4)}$ = 37.95, p=0.0001). Unsuccessful attempts occurred on 27.0% of first trials compared to 12.5 % of second trials and 0 % for trials 3, 4 or 5.

DISCUSSION

The task of rising to the toes requires an initial backward COP displacement, achieved primarily by TA activation, to allow the body COM to fall forward. This initial postural adjustment is followed by a forward COP displacement, achieved by SO and GA activation and reduced TA activation, to arrest the forward movement of the body COM and move it upwards and over the toes (Clement et al. 1984; Diener et al. 1990; Kasai and Kawai 1994; Lipshits et al. 1981; Nardone and Schieppati 1988).

Postural threat reduced the magnitude and rate of postural adjustments and voluntary movement

The results of this study demonstrate that the CNS modified rise to toes behaviour in response to different levels of postural threat. These modifications appeared in both the anticipatory postural control and voluntary movement components of the task. The magnitude and rate of the COP APA as well as TA muscle activity were progressively reduced as postural threat increased with the most prominent alterations in control observed for the most threatening condition, rising to the toes when positioned at the edge of the high platform. The alterations in anticipatory postural control resulted in observable changes to the subsequent voluntary movement component of the task. The magnitude and velocity of the forward COP displacement as well as SO and GA muscle activity were progressively reduced as postural threat increased. Again, the most dramatic changes were observed for the most threatening level of postural threat. The combination of changes in EMG activity and COP control resulted in a progressive reduction of the magnitude and acceleration of the COM as postural threat increased. Reduced magnitude of forward COM movement, coupled with the observation of a backward shift in the initial COM position, would cause the absolute forward COM position to be located much further back away from the edge when performing the rise to toes task at the edge of the high platform.

It appears that the CNS adopts a more conservative strategy when threatened, reducing the magnitude of the postural adjustments and thus their potential destabilizing effects in the direction of the movement. This observation is similar to that observed under conditions of postural instability (Aruin et al. 1998). Furthermore, the CNS demonstrates increased caution during quiet stance (Adkin et al. 2000; Carpenter et al. 1999, 2001) and when responding to an external perturbation (Brown and Frank 1997).

Postural threat lengthened the duration of voluntary movement, but did not influence the relative timing of the postural adjustments and voluntary movement

The results of this study demonstrate that the CNS modified the duration of the voluntary movement component of the rise to toes task in response to different levels of postural threat. The time required to reach peak forward COP displacement was lengthened for the most threatening condition. Subsequently, the time required for the COM to reach the new position of support over the toes similarly lengthened. Although the duration of the COP APA was not significantly altered by level of postural threat, a trend for longer COP APA duration was observed for the most threatening level of postural threat.

The relative timing of lower leg muscle activation patterns were examined to provide further insight into CNS control of the rise to toes task. The order of muscle activation was the same across all levels of postural threat: TA was activated first, followed by SO and GA. The relative timing of the muscle activity (e.g., difference in timing from TA onset to SO onset or TA onset to GA onset) generating the initial postural adjustment and subsequent voluntary movement was not influenced by postural threat.

These observations suggest that when threatened, especially when rising to the toes at the edge of the high platform, the CNS increased the time taken to move the body COM to a new position of support over the toes. This is accomplished through a general slowing of the sub-components of the task; the relative timing of the sub-components of the task are preserved. This increase in duration is most likely related to the reduction in the rate and magnitude of the postural adjustments.

Alterations in postural control strategy provide a greater margin of safety but may compromise successful completion of the task

The CNS adopted a more cautious strategy when performing the rise to toes task as postural threat increased. First, the initial position of the COP and COM was moved further back away from the edge of the platform for the most threatening condition. Similar shifts in position away from the edge of the platform have been observed during quiet standing (Adkin et al. 2000; Carpenter et al. 1999, 2001) and in advance of a destabilizing perturbation (Brown and Frank 1997). These changes suggest the CNS selects a safer starting position further from the platform edge. When performing the rise to toes task under threatening conditions, this adjustment will reduce the chances that the COM will move out over the edge of the platform. There is some evidence to suggest that voluntarily leaning forward or backward prior to rising to the toes influences the timing and magnitude of postural adjustments (Diener et al. 1990).

The changes in the magnitude and rate of the postural adjustments and the subsequent movement to the new position of support over the toes provided a greater margin of safety but compromised the completion of the movement task. For example, an APA of insufficient magnitude may prevent the rise to toes task from being successfully completed. Absent or reduced APAs for individuals with PD or cerebellar dysfunction have been shown to compromise stability and the overall integrity of the movement task (Diener et al. 1990, 1992; Frank et al. 2000). It appears that when performing the rise to toes task when threatened, the task becomes less stable, evidenced by the increased number of crossings of the COM by the COP and the greater frequency of unsuccessful attempts to rise to the toes. These observations of decreased stability are also accompanied by changes in perception of stability. Participants reported being much less stable when performing the rise to toes task when threatened.

Although the postural control strategy selected by the CNS may at times compromise the rise to toes task in more threatening conditions, it may be more beneficial when considering the consequences of maintaining a similarly scaled APA. Aruin et al. (1998) have shown that in conditions of postural instability the CNS reduces the magnitude of APAs to limit the potential destabilizing effects from the APAs themselves. This is especially evident when the destabilizing effects of the task and postural adjustments are in the same direction. The primary danger when rising to the toes when threatened especially at the edge of the high platform, is the possibility of losing balance in the forward direction. A larger and more forceful APA would cause a greater acceleration and displacement of the COM in the forward direction. If this movement of the COM is not arrested adequately, loss of balance may occur and the participant may fall toward the edge of the platform. The cost associated with a large and forceful APA may be especially extreme for the most threatening condition as there is no option for stepping; when standing at the edge at the low height, participants could still step down to ground level (0.4-m) without great risk of injury. Reducing the rate and magnitude of the APA will allow the movement of the COM to be reduced and slowed with the final position achieved by the COM being further away from the edge of the platform. If the APA is of insufficient magnitude to destabilize the COM forward or the forward COP displacement is of insufficient magnitude to arrest the forward COM movement and move it upward, the CNS can maintain balance by simply returning to the initial support position. A return to the initial support position is observed in individuals with cerebellar dysfunction as the COM is not shifted sufficiently forward due to absent or reduced APAs (Diener et al. 1990, 1992).

Similar to our recent work on standing and postural responses to external perturbations under threatening conditions, the CNS selected a more cautious strategy to reduce the chances of the COM moving outside the base of support. For example, the movement of the COM during quiet standing is controlled more tightly (Adkin et al. 2000; Carpenter et al. 1999, 2001) and the movement of the COM in response to an external perturbation is reduced (Brown and Frank 1997). The strategy used for the rise to toes demonstrates that the CNS will employ a more cautious strategy, even one that may place the completion of the task at risk. The observations of changes in postural control are reflective of a more cautious but less stable control strategy in response to increasing levels of postural threat and could be attributed to a number of factors, for example, increased arousal or a change in perception, such as increased fear.

Increased physiological arousal and perceptions of decreased confidence and increased anxiety are associated with postural control changes observed on the rise to toes task

This study provides converging evidence from a number of different sources to explain the effect of postural threat or fear of falling on behaviour. Alterations in physiological arousal, perception, and postural control were observed as level of postural threat increased. The results of this study suggest that the increased physiological arousal and perceptions of decreased confidence and increased anxiety may be associated with changes in anticipatory postural control. Maki and McIlroy (1996) have shown that an increase in physiological arousal can lead to changes in postural control in humans while Lepicard et al. (2000) have demonstrated that the postural behaviour of anxious and non-anxious strains of mice differed when postural control was challenged. These two studies suggest that arousal and anxiety may act as potential modifiers of postural control. The converging evidence from a number of different sources provided in this study supports this view. For example, alterations in rise to toes behaviour observed in healthy young adults in response to increased postural threat were accompanied by increases in physiological arousal and perceptions of lower confidence and higher anxiety concerning balance and risk of falling. Significant but moderate correlations between postural control, physiological arousal and anxiety measures were observed. For example, COM peak acceleration was correlated with physiological arousal (r=0.46) and perceived anxiety (r=0.51) and APA peak velocity was correlated with physiological arousal (r=0.42) and perceived anxiety (r=0.52).

Increased physiological arousal and perceptions of lower confidence and higher anxiety, associated with an increased threat to posture, combined to produce a more cautious control strategy to reduce the risk of falling during the performance of the rise to toes task. These results suggest that postural threat or fear of falling does influence strategies for postural control during a voluntary rise to toes task in healthy young adults. Evidence of increased arousal and perceptions of lower confidence and higher anxiety as postural threat increased confirmed the manipulation of postural threat using surface height and step restriction modifications as an adequate tool to investigate fear-related effects on postural control.

Fear of falling may contribute to changes observed in rise to toes behaviour for individuals with balance disorders

The co-ordination of the rise to toes task has been examined for individuals with PD (Diener et al. 1990; Frank et al. 2000; Kaneoke et al. 1989) and cerebellar disorders (Diener et al. 1990, 1992). With PD, the magnitude of the initial postural adjustment is reduced and the relative timing of the muscle activity generating the initial postural adjustment and subsequent voluntary movement is disrupted leading to a less stable position of the COM over the toes. Individuals with cerebellar dysfunction reveal similar reductions in the APA magnitude and disrupted timing of the sub-components of the movement. Increased variability in rise to toes performance is also observed in the PD and cerebellar patients (Diener et al. 1990, 1992). While such alterations in postural control are assumed to be of physiological origin; fear of falling also may contribute to the change in postural control strategy observed. Fear of falling may be more prevalent for individuals with balance disorders when compared to healthy individuals of the same age and this fear may modify strategies for postural control.

The results of this study identified the effects of fear of falling on anticipatory postural control. The alterations in rise to toes behaviour in healthy young adults when threatened share both similarities and differences from those reported for individuals with balance problems. When threatened, the rate and magnitude of the postural adjustments and voluntary movement is reduced, the timing of the voluntary movement is lengthened but the relative timing of posture and voluntary movement events is preserved. In PD patients, the magnitude of the postural adjustments and voluntary movement were also reduced. However, instead of a general slowing in the overall pattern of behaviour, actual disruptions in the relative timing of the components of the behaviour were observed (Frank et al. 2000; Kaneoke et al. 1989). Similar alterations in magnitude, in some cases APAs were absent, were observed for cerebellar patients (Diener et al. 1992). Furthermore, the relative timing of the posture and voluntary movement events was disrupted and quite variable for individuals with cerebellar disorders (Diener et al. 1990, 1992). Our findings suggest that alterations in the relative timing of the muscle activity may reflect underlying pathology while alterations in the magnitude of the postural adjustments and voluntary movement may be magnified by a fear of falling. Thus, psychological factors such as fear of falling can play a role in modifying postural control during voluntary movement and must be considered when diagnosing and treating individuals with balance disorders.

CONCLUSIONS

Fear of falling often accompanies a balance disorder and it is important to both the diagnosis and treatment of the disorder to distinguish psychological and physiological influences on postural control. For individuals with balance disorders, physiological variables (e.g., deterioration of the balance control system due to the disease process) and/or psychological factors (e.g., fear) may lead to alterations to strategies for postural control. The results of this study show that postural threat or fear of falling does influence anticipatory postural control and voluntary movement when rising to the toes. Fear of falling may compound balance performance on voluntary movement tasks and lead to an increased risk of falling. Other tasks, such as step initiation, which require precise coordination between posture and movement components, have been investigated in patient populations (Burleigh-Jacobs et al. 1997) and may be influenced by fear of falling. Thus, it is critical to identify both psychological and physiological influences on postural control when assessing individuals with balance disorders or managing elderly individuals at risk for falls.

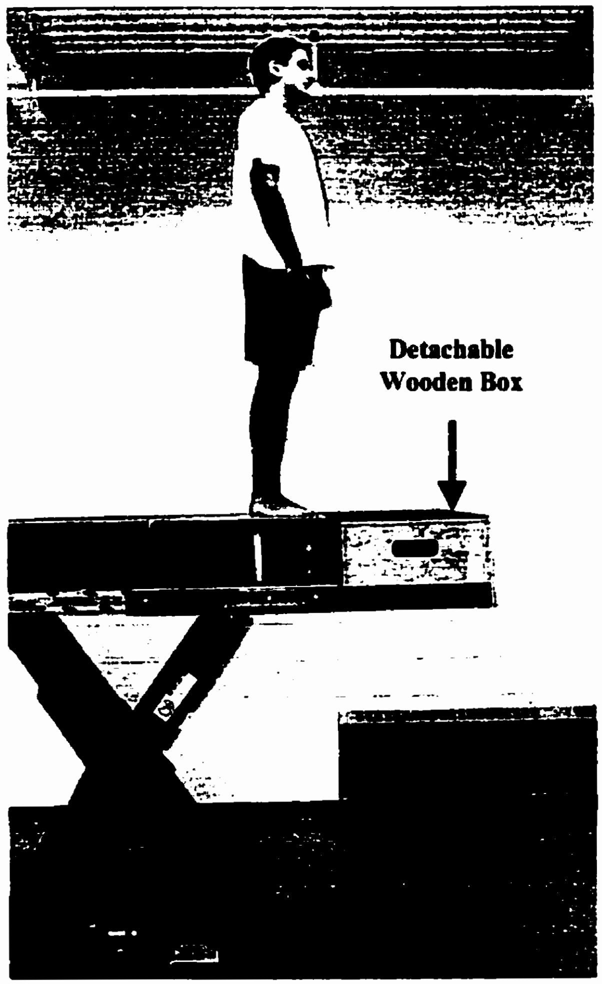

Figure 3.1. View of the hydraulic platform lift used to create four levels of postural threat. Surface height was set at 0.4 m (LOW) or 1.6 m (HIGH) above ground level. Participants stood either 0.5 m away from the edge of the lift (AWAY) or at the edge of lift (EDGE) when the wooden box mounted to the lift was removed. The present view shows a participant standing on the force plate at the HIGH AWAY condition.

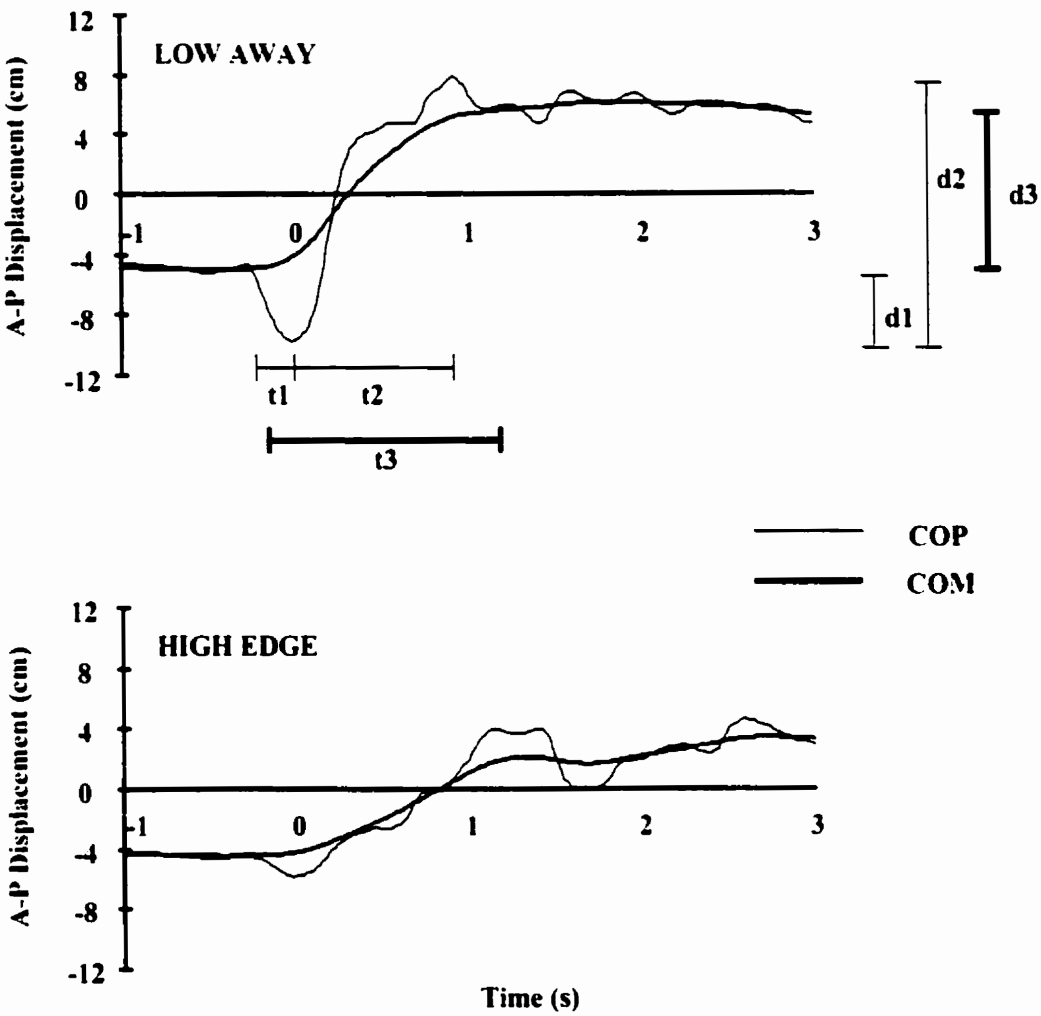

Figure 3.2. A-P COP (light line) and COM (dark line) profiles for LOW AWAY and HIGH EDGE conditions. For each condition, trajectories represent the mean of 5 rise to toes trials for one participant. The time at which peak COP backward displacement occurred was selected as the temporal reference point for all measures. Duration of the COP APA (t1) and duration of forward COP (t2) and COM (t3) movement were calculated. Magnitude of the COP APA (d1) and magnitude of forward COP (d2) and COM (d3) movement were determined. Peak backward velocity of the COP APA, peak velocity of the forward COP movement and peak acceleration of the forward COM movement were also calculated.

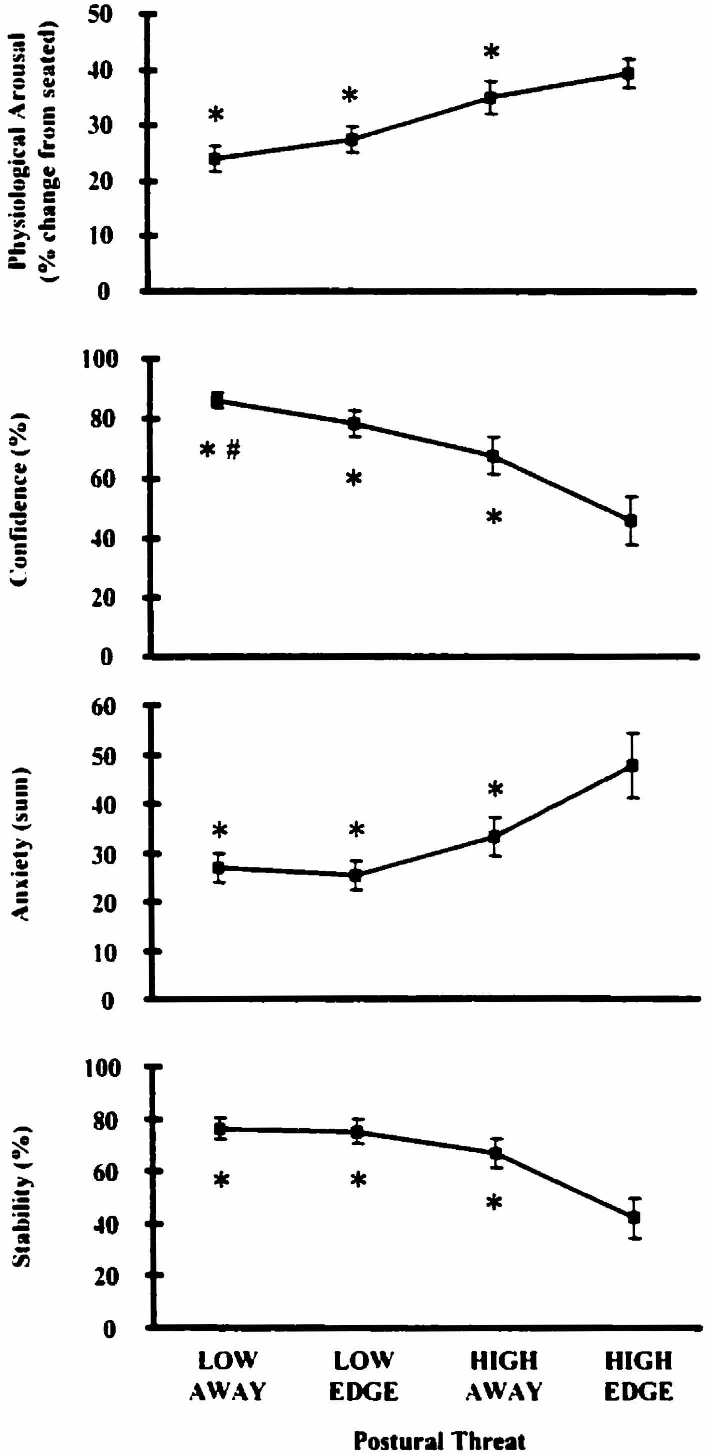

Figure 3.3. Mean physiological arousal values and perceived confidence, anxiety and stability ratings for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. Error bars represent ± 1 standard error. * represents different from HIGH EDGE while # represents different from HIGH AWAY.

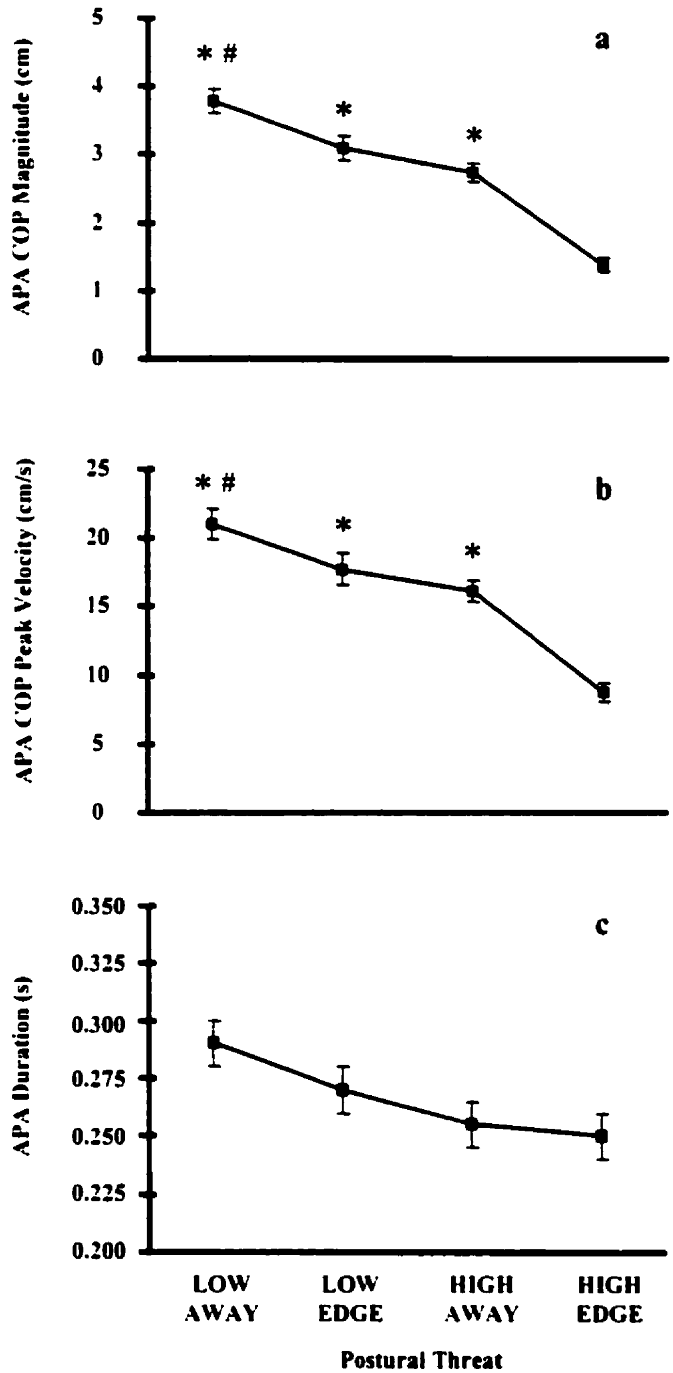

Figure 3.4. Mean COP APA magnitude (a), peak velocity (b) and duration (c) values for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. Error bars represent ± 1 standard error. * represents different from HIGH EDGE while # represents different from HIGH AWAY.

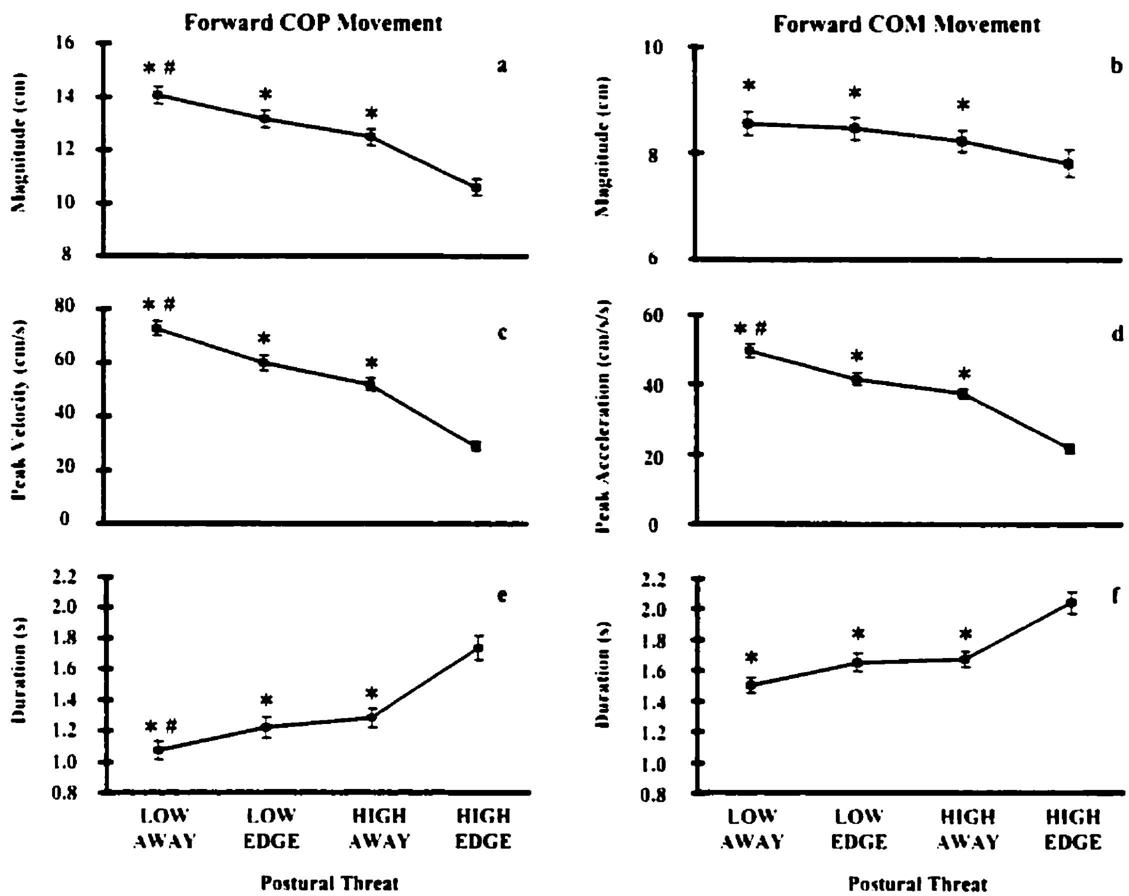

Figure 3.5. Mean forward COP magnitude (a), peak velocity (c) and duration (e) values and mean forward COM magnitude (b), peak acceleration (d) and duration (f) values for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. Error bars represent ± 1 standard error. * represents different from HIGH EDGE while # represents different from HIGH AWAY.

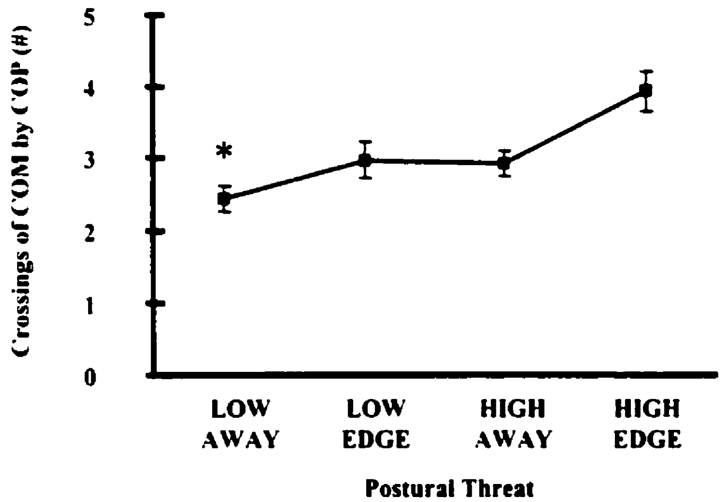

Figure 3.6. Mean number of crossings of the COM by the COP for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE threat conditions. Error bars represent ± 1 standard error. * represents different from HIGH EDGE.

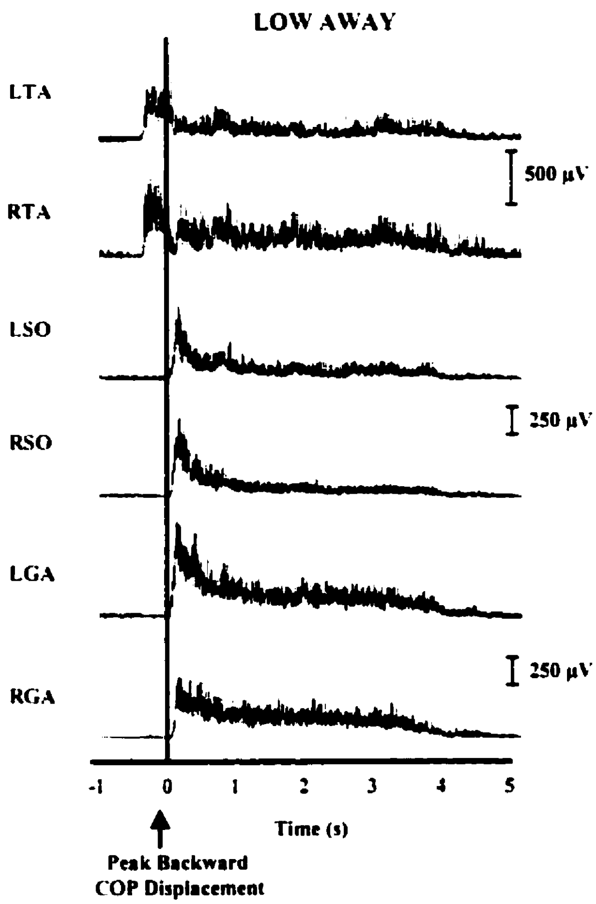

Figure 3.7. TA, SO and GA profiles for left (L) and right (R) limbs for LOW AWAY and HIGH EDGE conditions. For each condition, trajectories represent the mean of 5 rise to toes trials for one participant. Peak backward displacement of COP occurs at 0 ms.

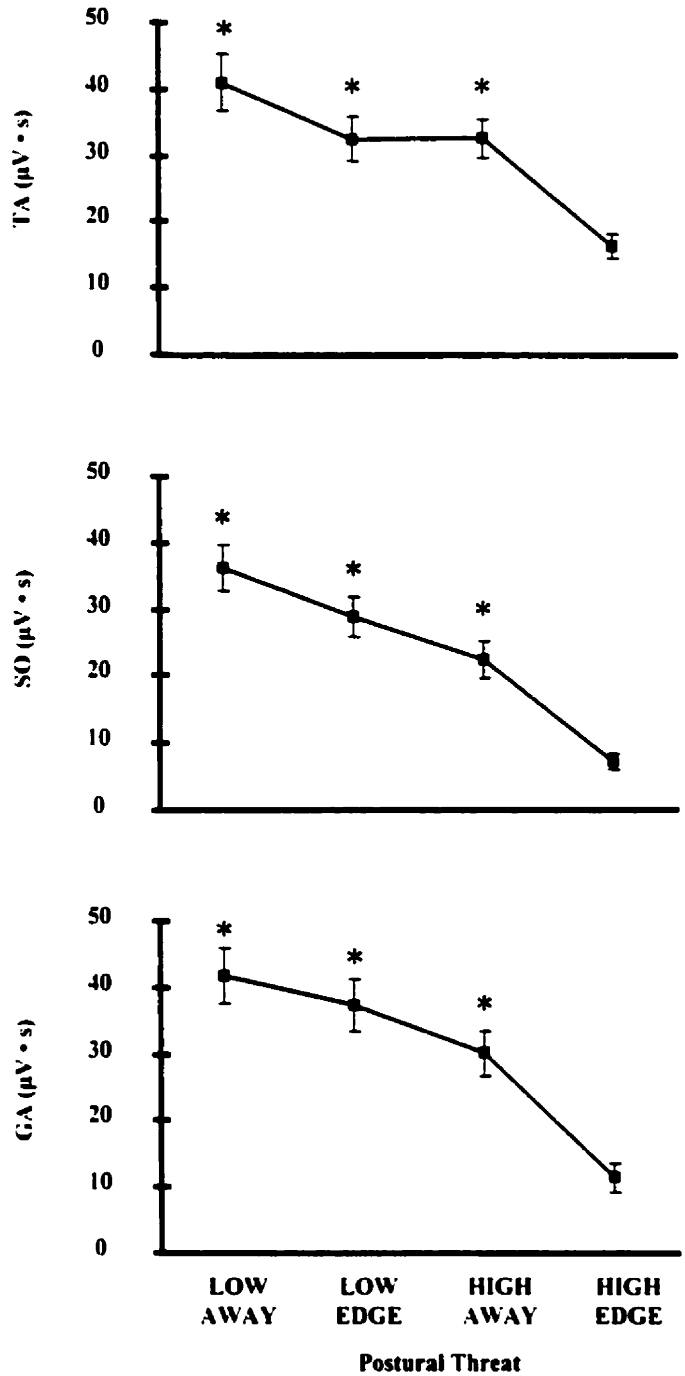

Figure 3.8. Mean TA, SO and GA integrated EMG activity level over a 250 ms interval from muscle onset for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. Error bars represent ± 1 standard error. * represents different from HIGH EDGE.

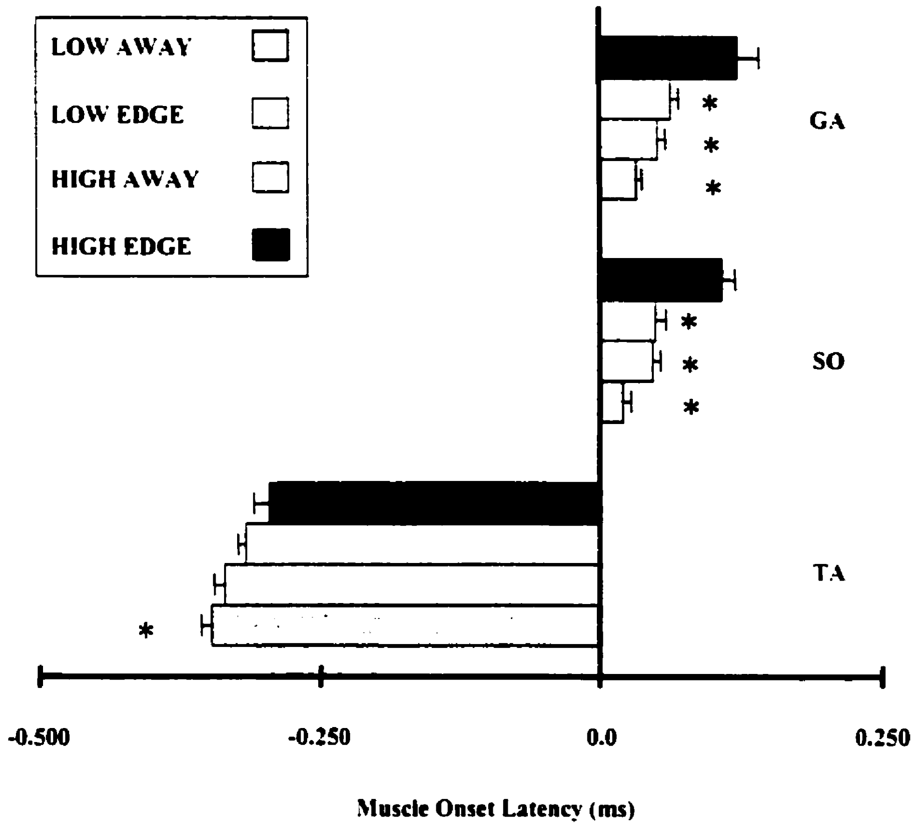

Figure 3.9. Mean TA, SO and GA muscle onset latencies for LOW AWAY, LOW EDGE, HIGH AWAY and HIGH EDGE conditions. Peak backward displacement of COP is at 0ms. Error bars represent ± 1 standard error. * represents different from HIGH EDGE.

CHAPTER 4

FEAR OF FALLING AND POSTURAL CONTROL IN PARKINSON'S DISEASE

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ABSTRACT

This paper discusses the results of two studies conducted to investigate fear of falling in Parkinson's disease (PD). The first study was designed to identify the prevalence of fear of falling in PD, as estimated using the Activities-specific Balance Confidence scale (Powell and Myers 1995). Individuals with PD reported lower confidence in their ability to perform a series of activities of daily living compared to healthy individuals of a similar age. The second study was designed to examine the relationship between fear of falling, disease severity and postural control in PD. Eight standing balance tests, each providing a different threat to posture, were performed. Patients who reported low confidence for performing activities of daily living demonstrated larger sway area values compared to those patients who reported high confidence; the most significant differences in sway area were observed for more challenging balance tests. Regression analysis demonstrated that fear of falling further explained variation in balance performance for more challenging tests compared to a measure of disease severity alone (i.e., Unified Parkinson Disease Rating Scale). The greater prevalence of fear of falling and its association with altered postural control in PD suggests that fear of falling must be considered in the assessment and treatment of postural instability in this population.

INTRODUCTION

Fear of falling is prevalent in the elderly (Arfken et al. 1994; Downton and Andrews 1990; Murphy and Isaacs 1982; Tinetti et al. 1988, 1994; Vellas et al. 1997; Walker and Howland 1991) and this fear may be even more common in a population known to have balance problems, such as individuals diagnosed with Parkinson's disease (PD). However, the prevalence of fear of falling in PD is unknown and its impact on the control of posture in this population has not yet been investigated.

Postural instability is well known to occur in PD. Alterations in strategies for the control of posture have been documented in this population during quiet standing tasks (Contin et al. 1996; Horak et al. 1992; Mitchell et al. 1995; Waterston et al. 1993), when responding to an unexpected destabilizing perturbation (Bloem et al. 1996; Chong et al. 1999; Horak et al. 1992, 1996; Schieppati and Nardone 1991) or when performing voluntary movements (Burleigh-Jacobs et al. 1997; Frank et al. 2000). These changes in postural control may increase the risk of falling (Bloem 1992) and evidence suggests that falls are highly prevalent for individuals with PD (Ashburn et al. 2001; Gray and Hildebrand 2000; Koller et al. 1989; Sato et al. 1999; Stack and Ashburn 1999). Alterations in postural control observed in PD are presumed to result from an underlying physiological cause associated with the disease process; however, psychological factors, such as fear of falling, also significantly contribute to these changes.

Although few studies have been conducted to examine the relationship between fear of falling and postural control directly, there is mounting evidence to suggest that fear does have observable effects on balance performance. Elderly who reported fear of falling demonstrated larger amplitude of postural sway when blindfolded and poorer scores when timed on a one-leg stance test compared to those who did not report fear of falling (Maki et al. 1991, 1994). Patients with phobic postural vertigo adopted a tighter control of posture characterized by smaller amplitude and higher frequency postural sway compared to normals (Krafczyk et al. 1999). A relationship between anxiety and postural performance has been identified in an animal model with more anxious strains of mice demonstrating poorer balance performance when compared to non-anxious strains of mice (Lepicard et al. 2000). Furthermore, in healthy young adults, fear of falling, induced by providing a significant threat to posture, has also been shown to influence postural control when standing (Adkin et al. 2000; Carpenter et al. 1999, 2001) and when responding to an unexpected push applied to the upper back (Brown and Frank 1997). If fear of falling is more prevalent in PD, it may have a dramatic influence on postural control in this population.

A further reason to investigate fear of falling effects on postural control in PD surrounds the evaluation of balance impairment in this population (Smithson et al. 1998). Alterations in postural control in PD remain difficult for the clinician to estimate subjectively. Most often, balance performance of patients is assessed by observing their standing upright posture, their ability to rise up from a chair and their response to a push or pull at chest level (i.e., retropulsion test); each of these tests is examined on the Unified Parkinson Disease Rating Scale (UPDRS). If fear of falling is prevalent for PD patients, this fear must be addressed when assessing balance performance and taken into consideration when counseling patients concerning their balance problems. Prevention of falls in PD is a critical health issue due to the serious consequences of falls for this population and older adults in general. Fear of falling can lead to restriction of activity and a loss of independence, which can significantly reduce quality of life (Vellas et al. 1997; Cumming et al. 2000; Howland et al. 1998; Lachman et al. 1998). Thus, understanding a potential fall risk factor, such as fear, is essential for identifying those individuals who may be at greater risk for falls.

This paper discusses results of two studies conducted to investigate fear of falling in PD. The first study identified the prevalence of fear of falling in PD patients compared to age-matched healthy individuals. The Activities-specific Balance Confidence (ABC) scale (Powell and Myers 1995; Myers et al. 1996), was used to estimate fear of falling. The scale based on Bandura's theory of self-efficacy (Bandura 1977, 1982 and 1997), measures balance confidence or efficacy in one's ability to perform different activities that challenge postural control. In this study, fear of falling is defined as low balance confidence or efficacy. It was hypothesized that fear of falling would be more prevalent in PD patients due to the alterations in the control of posture and the increased incidence of falling observed in this population.

The second study explored the relationship between fear of falling, disease severity and balance performance. Currently used scales (e.g., UPDRS) may not be able to estimate balance performance accurately. For example, the retropulsion test component of the UPDRS scale was not highly related to postural instability for individuals with PD (Bloem et al. 1998). Additional information regarding fear of falling may allow balance performance to be evaluated more accurately. Fear of falling and disease severity estimates were obtained from PD patients and these scores were related to postural control measures obtained for eight standing tests of different challenges. Although a relationship between disease severity and balance performance has been suggested (Contin et al. 1996; Waterston et al. 1993; Schieppati and Nardone 1991; Schieppati et al. 1994), both fear of falling and disease severity may be highly related to balance performance and to each other. It was hypothesized that fear of falling may contribute additional information along with knowledge of the severity of the disease to explain the variation in the control of posture for these standing tests. The converging evidence from clinical scores (UPDRS), psychophysical reports (ABC) and postural control measures may provide insight into understanding how fear of falling influences control of posture in PD patients.

STUDY A: Prevalence of Fear of Falling in Parkinson's Disease

METHODS

Participants

Fifty-eight patients (19 females, 39 males, mean ± SD age = 66.2 ± 9.3 years) from the Movement Disorders Clinic at the London Health Sciences Center diagnosed with idiopathic PD and thirty age matched healthy controls (16 females, 14 males; mean ± SD age = 66.7 ± 8.1 years) were recruited. The average disease duration since diagnosis was 6.5 ± 4.9 years. Patients with dyskinesia, significant musculoskeletal problems or other neurological disorders were excluded from the study. All participants were living in the community and were ambulatory. The University of Waterloo and University of Western Ontario Office of Research Ethics approved all experimental procedures.

Procedure

Each participant completed the ABC scale (Powell and Myers 1995; Myers et al. 1996). For this scale, participants rate the degree of confidence they have for completing sixteen activities of daily living (ADLs) without falling. The scale ranges from 0 % reflecting no confidence to 100 % reflecting complete confidence. The ABC scale was expanded from the Falls Efficacy Scale developed by Tinetti et al. (1990) to include ADLs of different difficulty levels. The scale was designed specifically to detect loss of balance confidence or fear of falling in individuals of different functional levels, especially those individuals who may be more active. The scale includes both walking and reaching-oriented activities that challenge postural control and activities that are performed both indoors and outdoors. PD patients were instructed to complete the questionnaire considering that they were performing the activity when on their anti-parkinson medication, essentially in their perceived optimal medication state. Mean ABC score across all sixteen items was used to estimate the degree or intensity of fear of falling. The Kruskal-Wallis test was performed to compare group differences between PD patients and healthy controls for mean ABC score. Furthermore, each of the sixteen items comprising the ABC scale was examined separately.

Self-reported fall history was also obtained for the three months prior to the testing session for all participants. Participants were asked to report the number of times they had fallen and also to report the activity that they were engaged in when the fall occurred. Participants were grouped into two categories: fallers or non-fallers. A chi-square test was performed to examine group differences between fallers and non-fallers. Mean ABC score for self-reported fallers and non-fallers was compared using the Kruskal-Wallis test.

RESULTS

Activities-specific Balance Confidence Scale

There was a significant difference between patients and healthy controls for mean ABC score ($p<0.01$). PD patients reported lower confidence in their ability to avoid falling during ADLs (mean ± SD = 68.7 ± 22.1 %) compared to healthy controls (mean ± SD = 93.2 ± 6.7 %). Mean confidence scores for each item of the sixteen-item ABC scale are presented in Figure 4.1. This figure provides an indication of the types of ADLs that resulted in reports of lower confidence. All sixteen items were significantly different between patients and controls ($p<0.01$). Several items, including reaching when standing on tiptoes (66.7%), reaching when standing on a chair (51.5%), getting in and out of a car (67.9%), walking in a crowd (65.8%), walking and being bumped (63.3%), using an escalator without holding a railing (53.0%) and walking on an icy sidewalk (41.7%) revealed dramatic decreases in confidence for PD patients compared to controls. Three of these tasks also produced reports of lower confidence in healthy controls: reaching while standing on a chair (87.6%), using an escalator while not holding the railing (86.4%) and walking on an icy sidewalk (74.6%). However, the level of confidence reported for these tasks did not drop significantly below the level of confidence reported by PD patients for any of the sixteen questionnaire items.

Self-reported falls

A significantly greater percentage of PD patients (45 %, 26 of 58) reported having fallen in the past three months compared to healthy controls (13%, 4 of 30) ($p<0.05$). Furthermore, PD patients who had reportedly fallen in the past three months were less confident (mean ABC score = 57.53%) compared to those who had not fallen (mean ABC score = 78.76%). Figure 4.2 shows the distribution of mean ABC scores for fallers and non-fallers. The most frequent activities in which individuals were engaged when a fall occurred were tripping or turning when walking and bending movements.

STUDY B: Fear of falling effects on balance performance in Parkinson's disease

METHODS

Participants

Twenty-one of the fifty-eight PD patients who participated in Study A (5 females, 16 males, mean ± SD age = 67.1 ± 8.8 years; disease duration = 6.6 ± 4.4 years) volunteered to participate in the second study which investigated the influence of fear of falling on stationary control of posture in PD (Table 4.1). All balance testing was completed in the Movement Disorders Clinic at the London Health Sciences Center. Each participant, informed of the experimental procedures, provided written consent prior to the testing session. The University of Waterloo and University of Western Ontario Office of Research Ethics approved all experimental procedures.

Procedure

Patients were tested approximately one hour after they had taken their anti-parkinson medication.

Unified Parkinson's Disease Rating Scale and Activities-specific Balance Confidence Scale

Each patient was assessed on the motor component of the UPDRS to provide an estimate of disease severity. The UPDRS motor score uses a five-point scale ranging from 0 (normal) to 4 (severely affected) with a minimum score of 0 and a maximum score of 108. The UPDRS motor score was further divided into seven sub-components: speech, facial expression, tremor, rigidity, repetitive tasks, posture and gait and bradykinesia. The posture and gait sub-score, which could range from 0 to 16, was used to estimate the change in balance and gait performance due to the severity of the disease process. The mean ABC score was used to determine balance confidence which was then used to estimate a patient's fear of falling; this measure was obtained previously for each of the 21 patients in Study A.

Standing Balance Tests

Patients performed a series of eight balance tests: normal stance with eyes open (EO), eyes closed (EC) or EO with the threat of a push or pull at shoulder level (THREAT); feet together stance with EO, EC or THREAT; normal stance on foam support with EO (FOAM); and one-legged stance with EO (1LEG). Each balance test was selected in an attempt to provide a different challenge or threat to posture through the manipulation of visual and proprioceptive information, changes in stance width or base of support or the introduction of an external threat to posture.

Patients stood on a force plate for each balance test. The duration of each standing trial was 60 s except for the one-legged standing task, which was performed for a maximum duration of 20 s. Patients were instructed to stand quietly on the force plate with their arms at their sides. For the normal stance condition, participants were asked to stand in a comfortable position on the force plate with no restrictions placed on their stance width. The feet together stance condition required patients to stand on the force plate with the first metatarsals and heels touching restricting the width of their base of support. The toes were placed at the anterior edge of the force plate for both the normal and feet together stance conditions. Once established, foot position was traced to maintain the same stance position for each normal or feet together stance trial. For all EO tests, patients were instructed to fixate on a target located 2 m in front of them at eye level. For all EC tests, patients began by fixating on the target and then were asked to close their eyes. For the FOAM test, a dense foam cushion, with the same dimensions as the force plate, was placed on the force plate to reduce the accuracy of proprioceptive information received from the lower limbs. For the THREAT condition, patients were instructed that at some point during the standing trial they might be pulled or pushed off balance at the shoulder level. For the one legged stance test, patients were instructed to stand on whichever leg they preferred but were asked not to rest the elevated limb against the stance limb during the balance test. The average duration of two attempts was used. At the completion of each trial, participants were seated and provided a five-minute rest period.

Balance Measures

Ground reaction force and moment of force signals were collected from the force plate with a frequency of 20 Hz. Centre of pressure (COP) was calculated in the anterior-posterior (A-P) and medial-lateral (M-L) direction for each 60 s record. COP measures can provide insight into how the central nervous system (CNS) is controlling the movement of the centre of mass (COM) as the COP tracks and controls the movements of the COM within the base of support when quietly standing. The difference between the COP and COM is highly correlated with the horizontal acceleration of the COM; changes in COP displacement will directly influence the displacement of the COM (Winter et al. 1998).

A variety of summary measures can be used to describe COP control (Prieto et al. 1996). In this study, mean position (MP), mean distance (MD), mean velocity (MV), standard deviation (SD) and mean power frequency (MPF) of the COP signal in both the A-P and M-L directions were determined. Mean position represented the average position of the COP over the 60 s record and was referenced in the A-P direction to the position of the ankle joint as calculated from foot length and heel to ankle length anthropometric measurements. Mean distance represented the average distance from the mean COP while mean velocity represented the average velocity of the COP. Following removal of the mean position value, the COP signal was filtered with a dual-pass Butterworth filter with a 5 Hz cutoff frequency. The SD of the COP signal was calculated to provide a measure of amplitude variability. A fast Fourier transformation of the COP signal followed by a MPF analysis was completed to provide an estimate of the average frequency contained within the power spectrum. Furthermore, sway area of the COP, used to describe the area of the stabilogram, was calculated by estimating the area enclosed by the COP per unit of time (Prieto et al. 1996).

Perceptions of confidence, fear of falling, stability and difficulty related to the balance test

Prior to each balance test, patients rated their confidence in their ability to maintain their balance and avoid a fall during the balance test. Following each balance test, patients were asked to rate how fearful and also how stable they had felt standing during the test. The fear of falling rating included a series of questions addressing, for example, whether patients felt anxious, nervous, tense or fearful of falling during the balance test. Postural stability ratings were obtained using the example of Schieppati et al. (1999). After completing the entire series of tests, balance test difficulty ratings were obtained as patients were asked to rate how difficult they perceived each task to be. All rating scales ranged from 0 % (low levels of confidence, fear, stability, difficulty) to 100 % (high levels of confidence, fear, stability, difficulty).

Statistical Analysis

Fear of falling or balance confidence effects on the control of posture in PD patients were examined by creating two groups based on reported fear of falling as estimated from the mean ABC score. The ABC score was considered to represent general balance confidence and reflect level or degree of fear of falling. Patients were separated into two groups based on their ABC score falling either above or below the median ABC value for all patients. A high confident/low fear (LOW FEAR) group, which included patients with an ABC score of 65.6 % or above (n=11) and a low confident/high fear (HIGH FEAR) group, which included patients with an ABC score below 65.6 % (n=10), were created. For each balance test, differences in perceptions of confidence, fear, stability and difficulty as well as balance performance were examined between the two groups using Kruskal-Wallis tests. Correlations were performed between the different balance measures to reduce the number of dependent variables used to estimate balance performance. As sway area was highly correlated with all other COP measures (range r = 0.55 to r = 0.99), this measure was selected to represent balance performance.

Regression analyses were used to examine the contribution of the UPDRS - posture and gait score and the mean ABC score to explaining the variation in balance performance, as estimated by sway area, for each balance test. In these analyses, disease severity was controlled for by forcing the UPDRS - posture and gait score into the regression model first. The ABC score was then entered to determine its contribution to explaining the variation in sway area.

RESULTS

Perceived confidence, fear, stability and difficulty for LOW FEAR and HIGH FEAR groups

Different challenges to postural control altered the perception of confidence, fear of falling, postural stability and balance test difficulty in PD patients (Figures 4.3-4.6). The normal stance EO test was perceived as the least threatening condition while the normal stance FOAM and 1LEG tests were generally perceived as the most threatening conditions. Patients also perceived the test as more threatening when the base of support was narrowed as in the feet together tests.

These perceptions of confidence, fear of falling, postural stability and balance test difficulty were significantly different for LOW FEAR and HIGH FEAR groups across the majority of balance tests (Table 4.2). Patients who reported high fear levels (low confidence) on the ABC scale felt less confident, more fearful and less stable across all balance tests and also perceived the balance tests to be more difficult when compared to those patients who reported low fear (high confidence) on the ABC scale (Figures 4.3-4.6).

Balance performance for LOW FEAR and HIGH FEAR groups

Despite differences in perceptions of confidence, fear, stability and difficulty between HIGH FEAR and LOW FEAR groups for all balance tests, only four of the eight balance tests showed significant differences in balance performance (Table 4.2). Sway area for the HIGH FEAR group compared to the LOW FEAR group was increased by 56.3 % for normal stance FOAM test, 84.6% for feet together stance EO test and 98.0% for feet together stance EC test. Furthermore, duration of one-legged standing was 118.3 % less for the HIGH FEAR group compared to the LOW FEAR group (Figure 4.7).

Relationship between fear of falling, disease severity and balance performance

The relationship between ABC (estimate of fear of falling), UPDRS - posture and gait (estimate of posture and gait impairment resulting from the disease process) and sway area of the COP (estimate of balance performance) was examined using regression analysis. Correlations between UPDRS - motor score and sway area and ABC score and sway area for each balance tests are presented in Table 4.3.

Results of the regression analysis for each balance test are presented in Table 4.4. Of note, ABC score was highly related to UPDRS - posture and gait score ($R^2 = 0.81$) (Figure 4.8). PD patients with greater degrees of balance and gait impairment reported lower confidence in their ability to avoid falling during ADLs.

The variation in sway area was not well explained by UPDRS - posture and gait score for the normal stance with EO, EC, or THREAT tests or the feet-together stance with THREAT test. The UPDRS - posture and gait score did explain some of the variation in sway area for the normal stance FOAM (28 %) test and the feet together stance EO (24%) and EC (28%) tests, although the model for each of these tests was marginally significant (near p=0.05). The UPDRS - posture and gait score did explain a large amount of the variation in stance duration for the 1LEG test (50 %).

When added to the regression model, the ABC score did contribute additional information toward explaining variation in sway area for the normal stance EO and EC tests and the feet-together stance EC, EC, and THREAT tests (Refer to Table 4.2 - partial R^2 values for ABC scores). ABC score did not contribute additional information toward explaining the variation in sway area for the normal stance THREAT or FOAM tests. Additionally, although related to stance duration for the 1LEG test (r=0.70), ABC did not contribute any additional information toward explaining the variation in stance duration.

For 5 of the 8 balance tests, the ABC score provided additional information toward explaining the variation in balance performance. This result suggests that the ABC score and UPDRS - posture and gait score can explain a greater amount of variation in balance performance than that provided by the UPDRS - posture and gait score alone. For example, together, the ABC and UPDRS - posture and gait scores can explain 33% of the variation in sway area for the normal stance EO test, 56% of the variation in sway area for the normal stance EC test, 35% of the variation in sway area for the normal stance FOAM tests, 59 % of the variation in the feet-together stance EO test, 53% for the feet-together EC test, 41% of the variation in sway area for the feet-together THREAT test and 52% of the variation in stance duration for the 1LEG test. Thus, as UPDRS - posture and gait score increased (more severely affected), sway area was increased. Accounting for UPDRS - posture and gait score, as ABC score decreased (more fearful), sway area was increased.

DISCUSSION

Fear of falling is prevalent for individuals with Parkinson's disease

This study examined the prevalence of fear of falling in PD, a population known to have postural disability. The results indicate that fear of falling is more prevalent for PD patients when compared to healthy individuals of a similar age. PD patients reported less confidence in their ability to perform ADLs without falling, possibly due to less confidence in their balance abilities related to deficits in postural control. This fear might further exacerbate these actual changes to the postural control system leading to additional alterations in strategies for postural control and increasing the risk for falls. Although, a small amount of fear may provide for increased caution in these patients, a great amount of fear may produce changes in behaviour such as activity restriction. loss of independence and reduced quality of life. For example. postural instability in PD has been shown to be related to reduced quality of life (Schrag et al. 2000, 2000). These changes in behaviour may further alter strategies for postural control. Thus. fear of falling presents serious consequences for this population.

Falls occur more often for individuals with Parkinson's disease

A greater number of individuals with PD reported more falls compared to healthy individuals of a similar age. Furthermore. fear of falling was associated with self-reported falls for PD patients over a three-month period prior to the study: individuals diagnosed with PD who reported more fear of falling fell more often than those patients who were less fearful of falling. A fall can result in a number of physical complications such as fractures. but also psychological complications. such as fear of falling. A patient with PD may physically recover from a fall but may develop a fear of future falls causing them to restrict their activities due to actual or perceived changes in their balance and gait performance. Although we cannot comment on whether falling caused the reports of higher fear of falling in our population or whether this fear was present prior to the fall occurrence. research has shown fear of falling to be associated with an increased fall risk. Prospective examination of the influence of fear of falling on the health status of older adults showed fear was associated with a greater risk of falling, diminished ability to perform ADLs and reduced quality of life (Cumming et al. 2000). Thus, a better understanding of fear of falling and its role in altering postural control and behaviour may aid in predicting who is at risk for falling in PD patients.

Fear of falling alters the control of posture in Parkinson's disease

The second study was designed to explore the relationship between fear of falling, disease severity and postural control in PD patients. The results show that fear of falling is highly related to disease severity, which can be expected. Individuals with PD who have a greater degree of balance impairment may be more likely to have reduced confidence in their balance abilities. Although, it is difficult to separate or distinguish the effects of fear of falling and disease severity on the control of posture. the results of this study suggest that identifying patients who are fearful of falling can aid in explaining balance performance.

The results revealed differences in the control of posture between patients who report higher fear (low confidence on ABC scale) for performing ADLs and those who report lower fear (high confidence on ABC scale) for performing ADLs. There were also differences in perceptions of confidence, fear, stability and difficulty between the two groups of patients and these differences were observed across the series of balance tests, from standing in a self-selected stance with vision to standing on one leg with vision. Patients who reported lower confidence on the ABC scale, also reported lower confidence, higher fear, felt less stable and perceived the balance tests as more difficult than patients who reported higher confidence on the ABC scale. The control of posture between the two groups only diverged when the balance tests became more difficult as observed when standing in a self-selected stance on a foam support, standing with the feet together on a normal support with or without vision or standing on one leg on normal support with vision. The high correlation between the disease severity rating and ABC scale may suggest that the differences in postural control are due to actual differences in disease severity, differences in fear levels or a combination of the two factors. The lack of performance differences between the two groups for the less challenging tasks, which still had provoked differences in perception between the two groups, argue that disease severity was not the sole cause of the observed differences in the more difficult tests. Thus, the challenge associated with the task appears to separate the two groups suggesting fear of falling does influence balance performance. The results of the regression analyses confirm these observations and show that fear of falling can provide additional information regarding balance performance on standing balance tests. Disease severity was not able to consistently explain variation in balance performance.

Stationary postural tasks were selected and their difficulty modified in order to provide a greater challenge or threat to balance. In situations with reduced visual or proprioceptive information or when the base of support is narrowed, increased fear of falling may be observed due to an inability to balance based on actual or perceived changes to the postural control system due to the disease process. More challenging balance tests for PD patients may elicit a greater degree of fear of falling, which may alter performance of these tests dramatically. Smithson et al. (1998) have shown that more difficult stance tasks (tandem stance, one-leg stance) and tasks which challenge postural control, such as the functional reach and a pull at the shoulder level, better discriminate between PD patients and healthy controls and PD patients who have fallen compared to those who have not fallen. Thus, fear effects on strategies for postural control may be especially evident when responding to an unexpected external perturbation or generating postural adjustments accompanying voluntary movement. It appears that a general fear of falling (ABC) based on the confidence one has in performing ADLs can moderately predict and aid in explaining the variation in balance performance on selected stance tests. The more challenging the task such as responses to an external perturbation and executing a voluntary movement may provide further avenues for exploring fear-related effects on balance performance in PD patients. Quantifying balance performance during the ADLs that comprise the ABC scale may provide further insight into this issue.

Fear of falling should be addressed in the assessment and treatment of postural instability in individuals with PD

The evaluation of postural instability in PD and the influence of fear of falling on this instability may provide valuable information relating to prediction of falls for this population. Fear may alter postural control in PD patients, markedly changing behaviour and leading clinicians to believe that balance performance is worse than it actually might be. Understanding the influence of fear of falling on postural control will provide direction for clinical assessment and treatment intervention for PD patients who are fearful of falling. This study provides evidence of a possible role of fear of falling on top of the disease process itself. This finding emphasizes the need to understand the role of fear on postural control in these patients as the effects of the disease and fear may be additive.

The identification of the effects of fear of falling on the control of posture for patients with PD suggests that this fear must be addressed when assessing and providing direction for PD patients. Counseling PD patients on their fear of falling may be beneficial. Addressing fear of falling and its consequences using specific interventions in fearful elderly has been the subject of recent work (Tennstedt et al. 1998). Furthermore, Baumann et al. (1999) and King and Tinetti (1995) have also suggested that efforts should be directed toward reducing fear of falling or increasing balance confidence. It is interesting to note that although balance performance was near to the level of more highly confident patients for relatively small challenges to postural control, perceptions of balance performance in the low confident group on these tests were still altered. If people are less confident in their ability to perform more challenging tests, they may reduce their activities. The direction should be toward providing PD patients with an understanding of their balance problems and their fear of falling. Restoring the patient's confidence in their ability to perform ADLs is essential in order to avoid the negative consequences of activity restriction and reduced quality of life.

The identification of fear of falling in PD patients, especially if this fear is restricting activity, may aid the clinician in evaluating balance performance and also tracking this performance over time. A comprehensive physical therapy model for PD patients was outlined by Morris (2001); it is recommended that assessment of balance and counseling patients about their balance problems should include evaluation and discussion of fear of falling.

Table 4.1. Clinical characteristics for each PD patient.

Patient	Sex	Age	Years since PD diagnosis	Falls in past 3 months	UPDRS motor	UPDRS posture-gait	ABC
P1	M	72	8	0	19.0	4.0	73.8
P2	M	64	6	0	13.5	0.5	91.9
P3	F	52	9	3	28.5	3.5	46.9
P4	M	65	18	1	14.0	1.0	88.1
P5	F	71	9	0	16.0	2.0	78.1
P6	M	49	3	1	19.5	3.5	65.0
P7	M	69	11	0	38.5	4.5	57.5
P8	M	61	5	0	29.5	1.5	93.1
P9	F	79	4	0	26.5	4.0	65.6
P10	M	66	2	0	27.5	3.0	70.0
P11	F	61	1	0	21.5	2.0	89.1
P12	M	78	6	0	44.5	5.0	59.4
P13	M	62	5	0	39.0	4.5	45.0
P14	M	61	5	0	22.0	2.0	83.8
P15	M	62	10	0	29.0	6.0	30.0
P16	M	60	12	0	26.5	3.5	68.8
P17	M	78	8	1	30.0	3.5	64.4
P18	M	67	2	1	17.0	3.0	64.4
P19	M	82	2	0	22.5	3.5	67.5
P20	F	73	11	3	42.5	8.0	10.0
P21	M	76	1	0	29.5	6.0	60.6

Table 4.2. Statistical differences between HIGH FEAR and LOW FEAR groups for each balance test. Measures included perceived confidence, fear of falling, stability and difficulty ratings as well as measures of balance performance; sway area for all normal and feet together stance tests and stance duration for the 1LEG stance test (** $p<0.01$; * $p<0.05$; # $p<0.10$)

Balance Test	Perceived Confidence	Perceived Fear	Perceived Stability	Perceived Difficulty	Sway Area or Stance Duration
Normal, EO	*	**	*	*	n/s
Normal, EC	*	**	*	n/s	n/s
Normal, THREAT	#	*	n/s	*	n/s
Normal, FOAM	*	**	*	#	*
Feet-together, EO	*	**	**	*	**
Feet-together, EC	#	**	*	*	*
Feet-together, THREAT	**	**	n/s	*	n/s
1LEG	n/s	#	*	**	**

Table 4.3. Correlations between UPDRS - posture and gait score and balance measure and ABC score and balance measure for each balance test. The balance measure was sway area for all normal and feet together stance tests and stance duration for the 1LEG stance test.

Balance Test	UPDRS - posture and gait and balance measure (r)	ABC and balance measure (r)
Normal, EO	0.29	-0.51
Normal, EC	0.23	-0.61
Normal, THREAT	-0.17	0.05
Normal, FOAM	0.53	-0.59
Feet-together, EO	0.49	-0.75
Feet-together, EC	0.53	-0.73
Feet-together, THREAT	0.24	-0.56
1LEG	-0.71	0.70

Table 4.4. Regression analyses for each balance test: variation in balance performance (sway area for all normal and feet together stance tests and stance duration for the 1LEG stance test) explained by UPDRS - posture and gait score alone and contribution of mean ABC score.

	Step 1	Step 2 ABC added	
Balance Test	**UPDRS - posture and gait (model R^2)**	**ABC (partial R^2)**	**UPDRS - posture and gait and ABC (model R^2)**
Normal, EO	0.09 (0.2539)	0.24 (0.0432)	0.33 (0.0643)
Normal, EC	0.05 (0.3881)	0.51 (0.0018)	0.56 (0.0045)
Normal, THREAT	0.03 (0.5520)	0.02 (0.6304)	0.05 (0.7480)
Normal, FOAM	0.28 (0.0429)	0.07 (0.2749)	0.35 (0.0753)
Feet-together, EO	0.24 (0.0566)	0.35 (0.0052)	0.59 (0.0030)
Feet-together, EC	0.28 (0.0541)	0.25 (0.0331)	0.53 (0.0159)
Feet-together, THREAT	0.06 (0.3989)	0.35 (0.0212)	0.41 (0.0448)
1LEG	0.50 (0.0002)	0.02 (0.3807)	0.52 (0.0009)

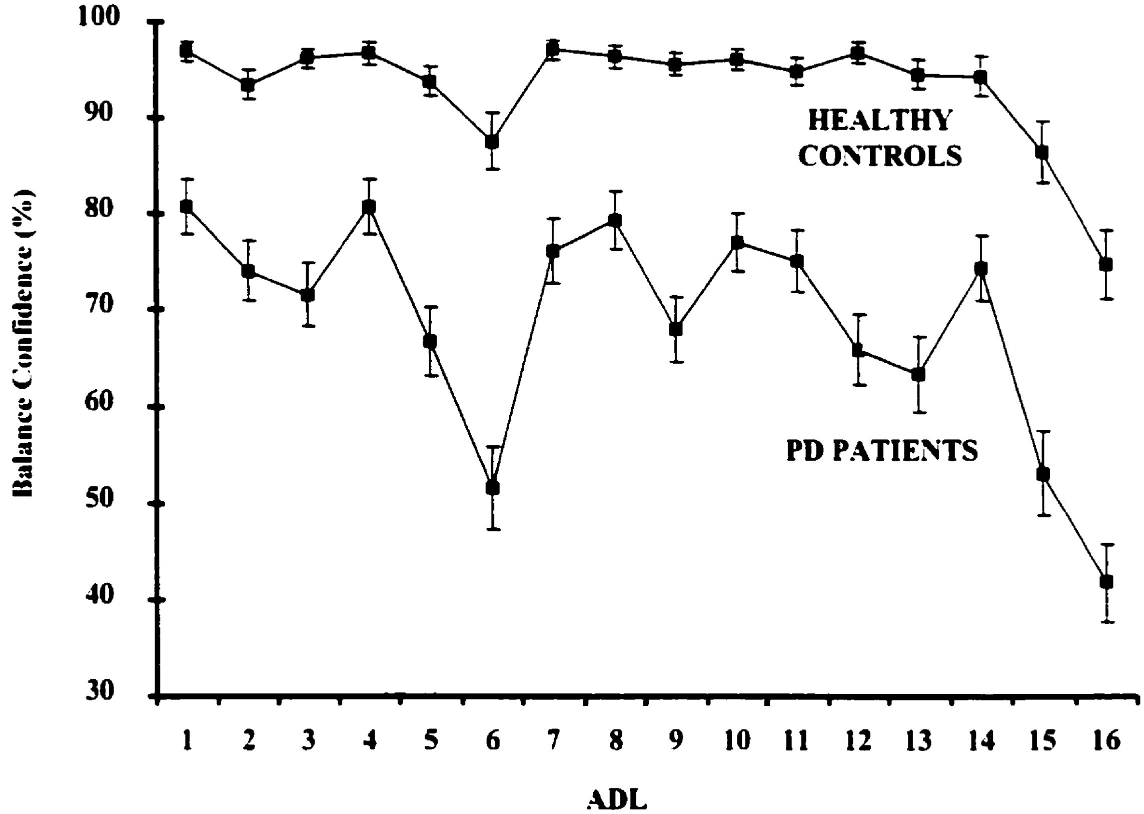

Figure 4.1. Reported balance confidence for each of the 16 ADLs comprising the ABC scale for PD patients and healthy controls. The ADLs included: walking around the house (1), walking up and down stairs (2), bending over to pick up a slipper (3), reaching at eye level (4), reaching on tiptoes (5), reaching while standing on a chair (6), sweeping the floor (7), walking outside to a parked car (8), getting in and out of a car (9), walking across a parking lot (10), walking up and down a ramp (11), walking in a crowd (12), walking and being bumped (13), using an escalator holding a railing (14), using an escalator and not holding a railing (15) and walking on an icy sidewalk (16).

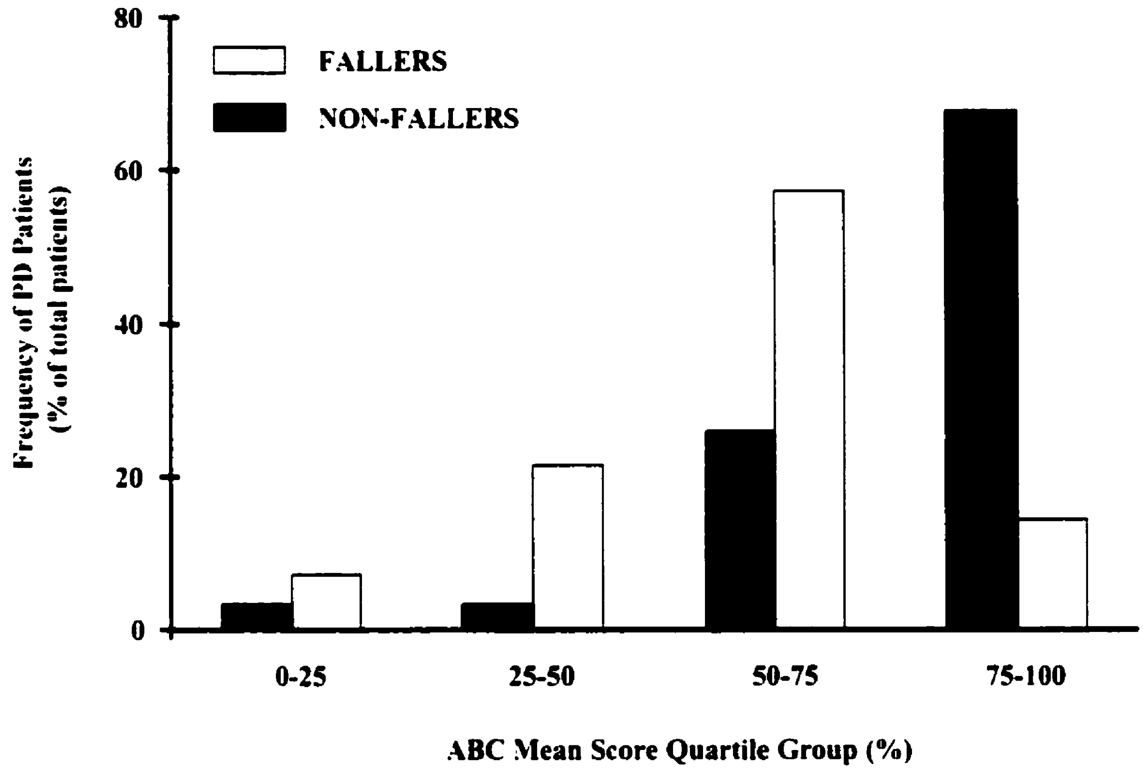

Figure 4.2. Frequency of patients who reported a fall in the past three months and those who did not report a fall grouped in quartile mean ABC score categories.

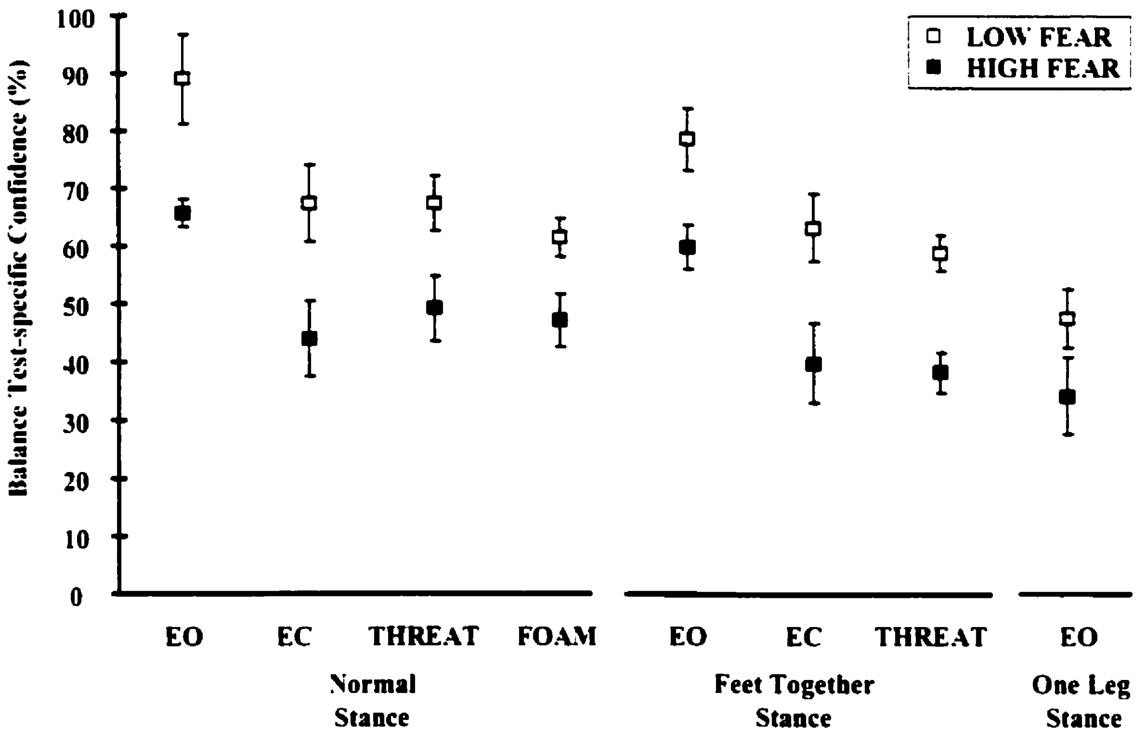

Figure 4.3. Mean balance test-specific perceived confidence report for HIGH and LOW FEAR groups for each balance test. Error bars represent ± 1 standard error.

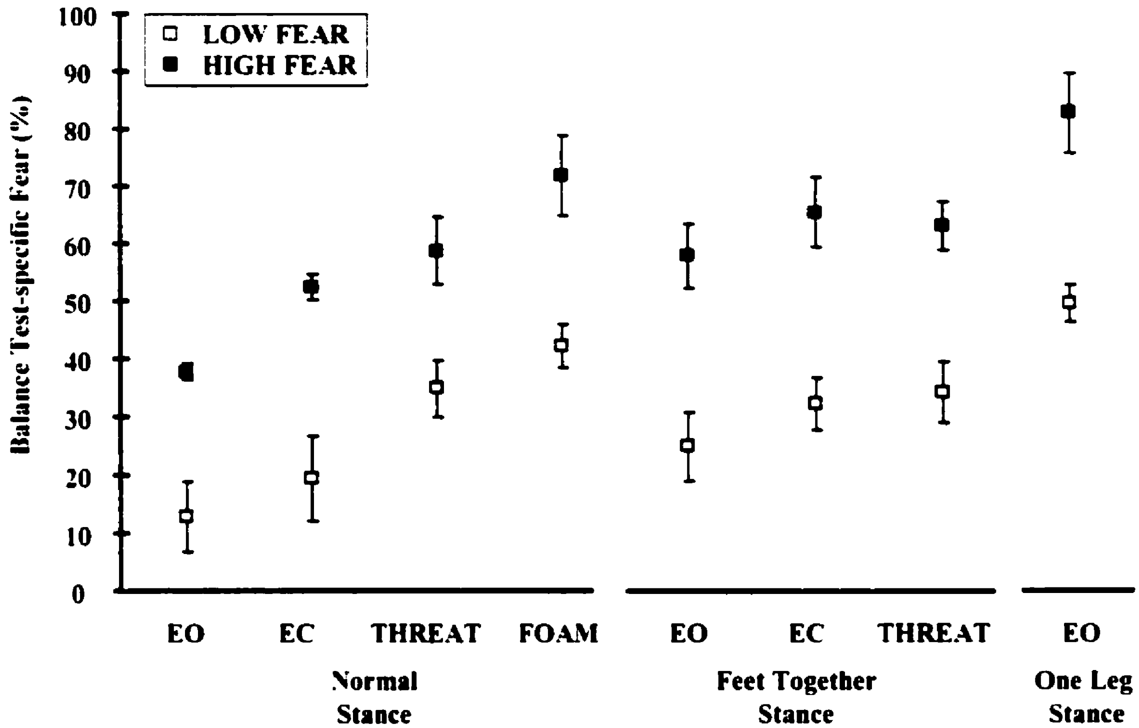

Figure 4.4. Mean balance test-specific perceived fear of falling report for HIGH and LOW FEAR groups for each balance test. Error bars represent ± 1 standard error.

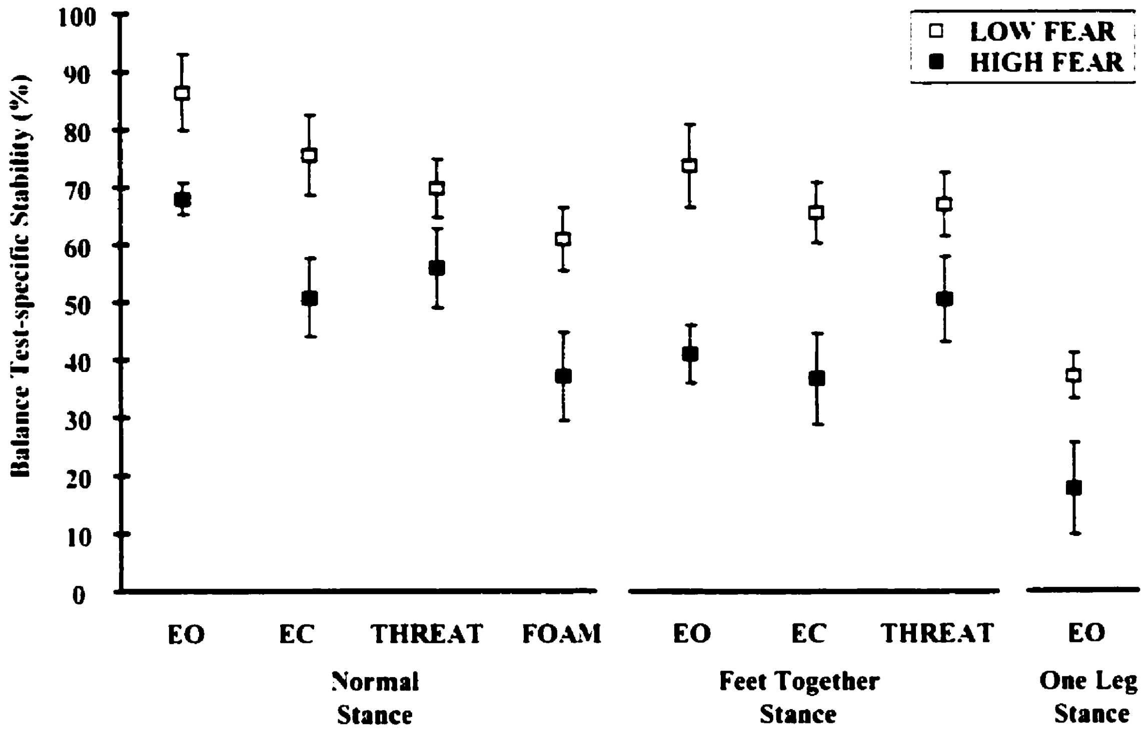

Figure 4.5. Mean balance test-specific perceived stability report for HIGH and LOW FEAR groups for each balance test. Error bars represent ± 1 standard error.

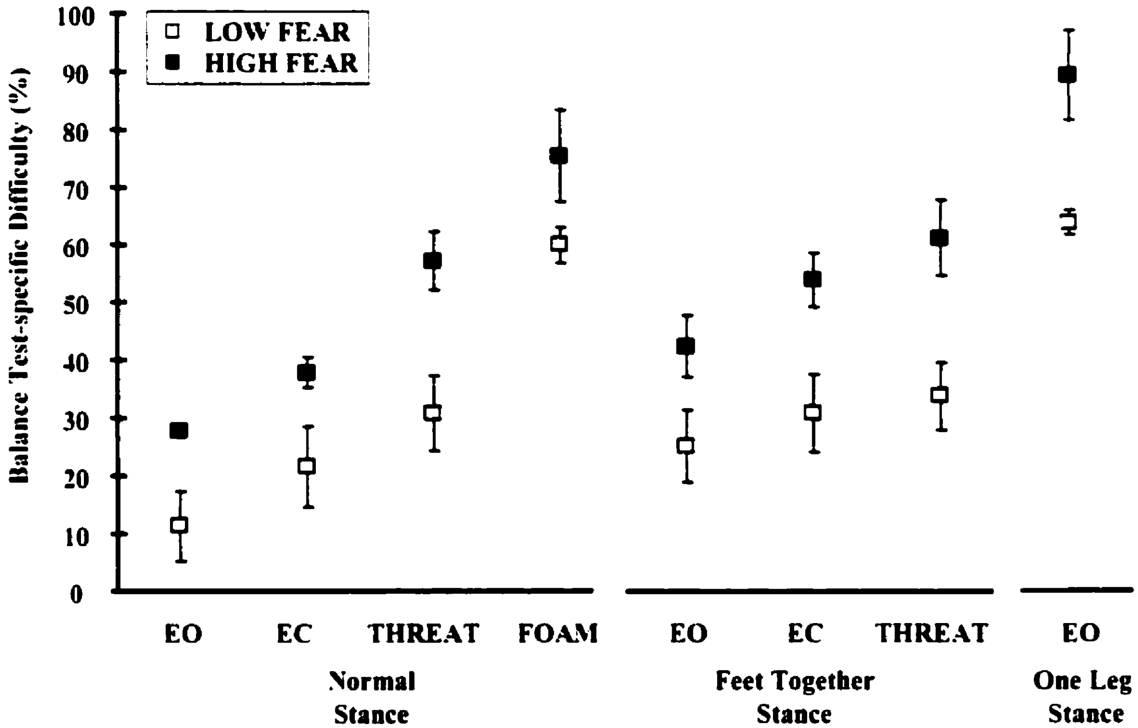

Figure 4.6. Mean balance test-specific perceived difficulty report for HIGH and LOW FEAR groups for each balance test. Error bars represent ± 1 standard error.

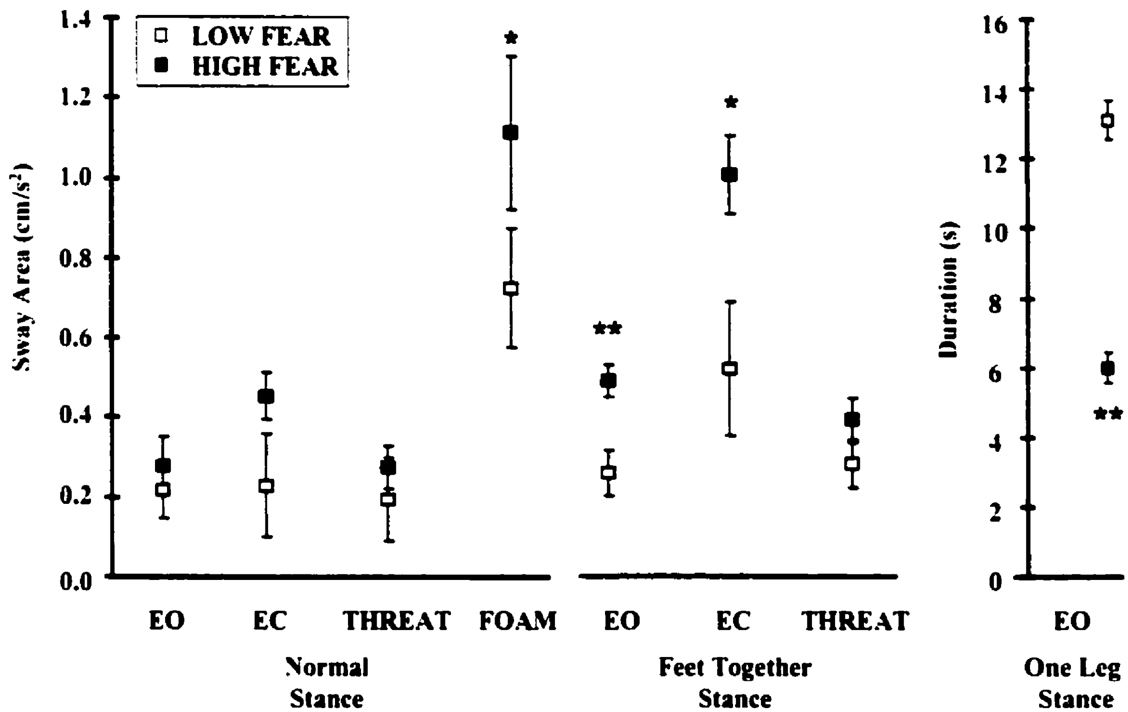

Figure 4.7. Mean sway area for HIGH and LOW FEAR groups for each normal and feet together balance test. Mean stance duration for HIGH and LOW FEAR groups for the one legged stance test. Error bars represent ± 1 standard error. ** represent $p<0.01$ while * represents $p<0.05$.

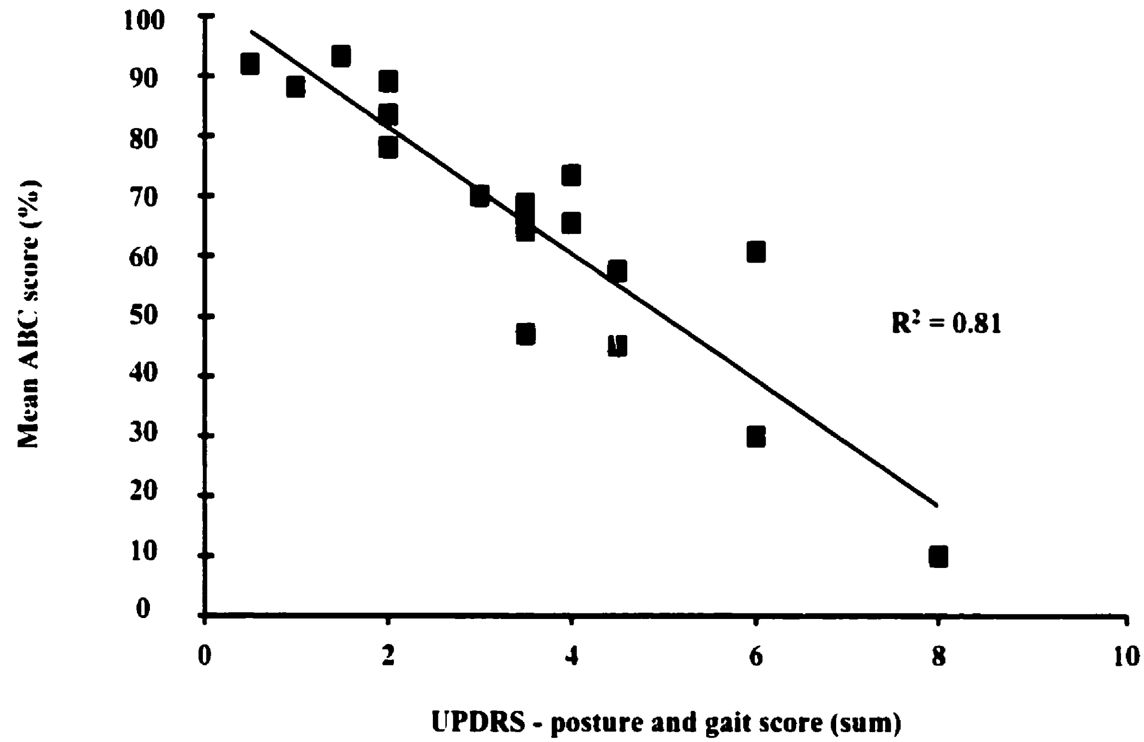

Figure 4.8. Relationship between UPDRS - posture and gait score and mean ABC score.

CHAPTER 5

DISCUSSION

The research presented in this thesis was directed toward understanding the influence of balance confidence on postural control strategies for the maintenance of upright stance. The results of the three studies provide converging evidence identifying balance confidence as a key psychological modulator of postural control. In response to a threat to posture, system-wide alterations, including changes in perceived balance confidence, perceived anxiety concerning balance performance, perceived stability and difficulty associated with the balance task and physiological arousal were observed. As well, significant modifications to postural control were documented.

Psychological and physiological changes accompany a perceived threat to posture

In this thesis, postural threat was modified through alterations to the standing surface height for healthy young adults and through alterations to the difficulty of the postural task for individuals with Parkinson's disease (PD). It is suggested that the appraisal of the threat to posture, influenced through balance efficacy, altered behaviour at several levels. For example, in healthy young adults, physiological arousal, as measured by skin conductance, increased and participants reported that they felt less confident, more anxious and less stable when performing the balance tasks under conditions viewed as more threatening. Furthermore, these changes appeared matched to the level or intensity of the perceived postural threat. Similar to healthy young adults placed in a threatening situation, individuals with PD reported that they felt less confident, more anxious and less stable when performing more challenging balance tasks, such as standing feet together with eyes closed or standing on one leg with eyes open, compared to less challenging balance tasks, such as standing feet apart with eyes open. Interestingly, low confidence and high anxiety reports were accompanied by reports of greater difficulty associated with the balance tests. Furthermore, these reports were related to a general confidence in the ability to perform activities of daily living (ADLs) without falling. Individuals with

PD who reported lower confidence for completing ADLs without falling demonstrated more dramatic changes in confidence, anxiety and stability than those who reported more confidence for completing these activities without falling. The findings from the three studies in this thesis argue that the appraisal of the threat to posture is influenced by level of balance efficacy and produces a wide range of behavioural modifications, including changes to the control of posture, as hypothesized in the proposed balance efficacy postural control model (Figure 5.1).

Postural control is precisely adjusted to the level or intensity of postural threat

In addition to the physiological and psychological modifications observed in response to a threat to posture, alterations to the strategies for the control of posture were also observed. The central nervous system (CNS) adjusted precisely the postural response depending on the level or intensity of the threat to posture in healthy young adults. Evidence of a scaled postural response was observed in both standing and voluntary movement tasks. During the standing task, the amplitude of postural sway progressively decreased while frequency of postural sway increased progressively as postural threat increased progressively. During the rise to toes task, the rate and magnitude of the anticipatory postural response was reduced progressively as postural threat increased progressively. These changes in anticipatory postural control resulted in a slower acceleration and reduced forward movement of the centre of mass (COM). For the standing task, a tighter control of posture may allow for an initial defensive response to an unexpected destabilizing perturbation; this strategy is hypothesized to facilitate immediate recovery of upright posture (Rietdyk et al. 1999; Winter et al. 1998). For the rise to toes task, the CNS modified the postural response to limit the chances of the COM moving too close to the edge of the platform. For example, the smaller and less forceful anticipatory postural response would limit the acceleration of the COM forward toward the edge of the platform. This strategy, if the anticipatory postural adjustment is not of sufficient magnitude, allows the body COM to return to its initial position of support over the toes. It appears that the CNS modifies control of posture precisely to minimize the disturbance to the body COM; this cautious approach provides for a greater margin of safety especially when the consequences of instability are severe (Brown and Frank 1997; Carpenter et al. 1999, 2001).

The observations of precisely scaled postural responses to level or intensity of postural threat provide interesting insight for those individuals who are fearful of falling. For example, these results suggest that a moderate degree of fear of falling may be beneficial for the older adult or the individual with a balance disorder promoting cautious strategies for approaching tasks that may present a significant threat to their balance. However, a great degree of fear of falling may prove debilitating, as inappropriate postural control strategies are selected or, to the extreme, individuals begin to restrict their activities (Lachman et al. 1998). Although speculative, a threshold may exist where the combination of changes in actual or perceived ability results in the selection of inappropriate postural control strategies heightening fall risk.

Prior experience of postural threat modifies postural control

The previous experience of performing a postural task in a threatening situation modifies the control of posture when performing the same task in a less threatening condition. For example, after experiencing the most threatening situation first, performance for subsequent less threatening conditions was characterized by a "looser" control of posture during standing. In contrast, when the threat to posture was experienced in sequential order from non-threatening to threatening, a "tighter" control of posture was observed for the initial less threatening conditions. Furthermore, performance on the first trial for both standing and rise to toes tasks differed from subsequent trials under the same level of postural threat. Specifically, more dramatic changes were observed for the first standing trial (decreased amplitude and increased frequency of postural sway) and the first rise to toes trial (reduced magnitude and rate of the anticipatory postural adjustment and movement onto the toes) compared to subsequent attempts at the same level of postural threat. Low confidence associated with the novelty or unexpected nature of the first trial may explain these differences; the initial performance of the task may provide the greatest threat to posture due to a lack of experience performing the task under these conditions.

Although no reports of perceived balance confidence, perceived anxiety or physiological arousal were measured in the study that systematically investigated prior experience of threat on postural control (Chapter 2), the observations from the second study (Chapter 3) suggest that balance efficacy may have influenced these changes. For example, for the participants who experienced postural threat in order from threatening to non-threatening, balance confidence and potentially arousal, fear or anxiety levels may have been reduced for the less threatening conditions after experiencing the most threatening condition first. The experience of success at the most threatening condition could provide different assessments or appraisals of the remaining conditions and increase balance confidence for performing the task; a primary feature of social-cognitive theory is the perceived control over the situation and the individual's coping skills (Bandura 1997; Cohen 1997; Maddux 1995). Whereas, for the participants who experienced postural threat in order from non-threatening to threatening, anticipation of the more threatening condition may have influenced postural control for the less threatening conditions. A similar explanation could explain the first trial effects observed in both the standing and rise to toes tasks. Thus, the control of posture was influenced by the order in which the threat to posture was experienced. These results support the effects of postural set on strategies for postural control (Horak and Macpherson 1996; Massion 1992).

Each of these findings has interesting application to balance assessment and intervention, particularly those assessments that allow for only a single attempt at performing a postural task. The individual may carry a certain amount of nervousness or anxiety associated with the balance assessment and performance could be much different from that observed under less threatening conditions. This "psychological baggage" may exaggerate the actual balance problem. Intervention techniques may focus on exposing individuals to situations in which they feel threatened, even though they are physically capable of performing the task. This is important for an older adult who may be so preoccupied with future difficult balance tasks or activities that this influences their performance on other less challenging tasks. This approach would allow these individuals to gain confidence under controlled situations and re-evaluate the appraisal of that specific threat to their posture (Baumann 1999; King and Tinetti 1995; Maddux 1995). Ideally, improvements in balance efficacy may produce changes in postural control strategies reducing the risk of falls when these tasks are performed. These results highlight the interactions between the different elements (concept of triadic reciprocal causation) presented in the proposed balance efficacy postural control model and emphasize the impact of experience in future appraisals of postural threat.

Postural threat modifies anticipatory postural control

This thesis provides evidence that anticipatory postural control is modified by postural threat. Previous work has shown that postural threat influences standing control of balance (Carpenter et al. 1999, 2001) and also postural recovery from a destabilizing push to the upper back (Brown and Frank 1997); however, it was unknown as to the effect of postural threat on anticipatory postural control strategies. The third chapter of the thesis describes the anticipatory postural response and how this could be modified by postural threat. The rate and magnitude of the anticipatory postural response was progressively reduced as the threat to posture increased. These changes resulted in significant alterations to the voluntary movement of the body COM forward and up to the new position of support over the toes. The movement was performed more slowly in situations of increased postural threat; however, no differences were revealed in the sequencing or relative timing of muscle activity underlying the movement. Critical to the performance of the task, alterations in the timing of the postural adjustment may have produced greater instability in the forward direction. The CNS employed a strategy to allow the body COM to return to a position of safety if the adjustment was of insufficient magnitude. These results demonstrate that strategies for postural control are modified by postural threat supporting previous results of changes in anticipatory postural control in response to the behavioural context in which the voluntary movement is performed (Massion 1992). The alterations in postural control in healthy young adults confirm that balance confidence does play a role in the selection of strategies for anticipatory postural control. These results highlight the need to understand the role of balance confidence on postural control under a wide range of postural tasks and also different challenges.

The basis for a neurological link between anxiety and postural control

The results of the thesis provide evidence for an association between anxiety, arousal, balance efficacy and postural control. In response to a threat to posture, system-wide alterations were observed; anxiety and arousal increased, balance efficacy decreased and strategies for postural control were altered. Furthermore, relationships between anxiety and postural control (Lepicard et al. 2000), arousal and postural control (Maki and McIlroy 1996) and balance efficacy and postural control (Myers et al. 1996) have been identified. It is possible that similar neural structures and pathways are responsible for these associations (Balaban and Thayer 2001).

Current theory suggests that the amygdala play a key role in the expression of anxiety and fear responses (Davis 1992; LeDoux 1998). The amygdala, a complex of four inter-connected nuclei, receives and processes sensory information from a specific stimulus and projects to areas of the brain to produce a context-dependent response. The target areas to which the amygdala distributes information are extensive and involve the expression of different behaviours depending on the threat and its context. Research using both animal and human models has provided insight into the structures and pathways responsible for the generation of the anxiety or fear response. For example, central gray projections are associated with freezing behaviour, lateral hypothalamic projections elicit autonomic responses such as increased heart rate, blood pressure or respiration and the bed nucleus of the stria terminalis projections produce, through the hypothalamus-pituitary-adrenal axis, a neuroendocrine response ultimately with the release of glucocorticoids (Lang et al. 1998; LeDoux 1996). The anxiety or fear response elicited by the amygdala to a potential threat may result in alterations to the control of posture. The modifications to strategies for postural control may occur in response to or in parallel to the anxiety or fear behavioural response. For example, increased heart rate, blood pressure, respiration can produce postural disturbances and signal the CNS to alter the control of posture (Jeong, 1991). Fridlund et al. (1986) observed that increased muscle activity levels were associated with increased arousal levels possibly due to activation of sympathetic nervous system pathways. Furthermore, the reduced amplitude and increased frequency of postural sway during standing observed in healthy young adults in response to a postural threat may be similar to the freezing behaviour observed in threatened animals (Blanchard et al. 1993).

Although these potential links between anxiety and postural control are important to consider, there are different mechanisms through which fear and anxiety might interact with the control of balance. For example, Balaban and Thayer (2001) recently reviewed the organization of the structures and pathways in the nervous system that may be responsible for the association between anxiety and postural control. These authors propose a model that considers the parabrachial nuclei as an important converging point for receiving sensory information related to a possible threat, integrating this sensory information and generating an appropriate response directed toward the specific target areas in the nervous system.

The observation of changes in postural control strategies in individuals with balance disorders and their association with anxiety disorders provides further evidence for the possible link between anxiety and balance control pathways. An additional projection of the amygdala is to the basal ganglia, specifically the globus pallidus and substantia nigra pars compacta nuclei (Balaban and Thayer 2001). This projection suggests a possible link between the anxiety and fear pathways and the motor pathways in the basal ganglia. This neuroanatomical link may be critical for understanding anxiety and fear effects in PD patients noted to have both deficits in postural control and increased anxiety levels (Shulman et al. 2001). Continued research to elucidate the common pathways between the anxiety and fear system and postural control system is crucial to understanding the impact of anxiety and fear on postural control.

Clinical relevance of fear of falling: Application for balance assessment and intervention strategies

The assessment of postural control in the elderly and individuals with balance disorders remains complicated, both due to the complexity of the postural control system and the multiple factors which lead to altered balance and falls (Berg 1989; Horak 1997; Morris 2000; Winter et al. 1990). Psychological factors may confound the assessment and treatment of balance problems and complicate the identification and prevention of falls in individuals who are at risk for falls (King and Tinetti 1995). Thus, a key application of the present thesis is to provide insight into developing strategies for balance assessment and fall prevention; essentially highlighting the need to address fear of falling or balance confidence in the prevention and treatment of falls.

The ability to determine the effects of balance confidence on postural control in a healthy intact system may provide insight for distinguishing psychological and physiological effects on postural control in the elderly and individuals with balance disorders. The interaction between psychological and physiological factors may account for the discrepancy in the literature concerning postural sway measures observed in patient populations and the elderly. For example, increased postural sway (Contin et al. 1996; Waterston et al. 1993), decreased postural sway (Horak et al. 1992) or no change in postural sway (Schiepatti and Nardone 1991) has been reported for individuals with PD compared to normal. Similar observations have been reported in the elderly and have been reviewed by Alexander (1994) and Maki and McIlroy (1996). Furthermore, an increased stiffness control of posture, characterized by decreased amplitude and increased frequency of postural sway was observed when healthy young adults were threatened. The same postural response was observed for patients with phobic postural vertigo, a psychogenic disorder. These results suggest that in an intact healthy physiologic system, anxiety or confidence may lead to the adoption of an increased stiffness control of posture. In fearful elderly, increased postural sway responses are observed especially for more challenging balance tests (Maki et al. 1991; Hughes et al. 1996). Furthermore, in this thesis, greater postural sway was observed for fearful PD patients. The selection of an increased stiffness control of posture in fearful elderly or PD patients may not be an effective control strategy, especially if their posture is challenged, for example, with a destabilizing perturbation. Although a stiffness strategy provides an initial line of defense for a healthy intact system (Rietdyk et al. 1999; Winter et al. 1998), the deficits in postural reactions observed in PD and the elderly (Bloem et al. 1996; Horak 1997; Horak et al. 1996) coupled with an increased stiffness control during standing may prove detrimental and increase the risk for falls. Furthermore, increased postural sway may facilitate alternate strategies such as stepping, if a loss of balance occurred (Maki and McIlroy 1996). The differences in the standing control of posture between healthy young adults when threatened and fearful PD patients or fearful elderly could be explained by the element of control or coping strategies for the balance task. Balance efficacy may be lowered in healthy young adults but their perceived control over the situation may still be relatively high. In contrast, an older adult or individual with PD may have lower balance efficacy coupled with a loss of perceived control over their ability to balance leading to greater alterations in balance control. Thus, fear of falling may have different effects on different populations due to the interaction of fear or confidence and the related pathology or deficit in the nervous system.

Concerning anticipatory postural control, changes in the magnitude of the anticipatory response were observed in healthy young adults, however the timing of the muscle activity was preserved. The response of PD and cerebellar patients showed alterations in the control of the magnitude and force of the anticipatory postural adjustments but also accompanying these changes were alterations in the timing of the underlying muscle activity. Thus, alterations in timing of the postural response may reflect actual pathology whereas alterations in the magnitude of the postural response may be compounded by fear of falling. Thus, it appears that postural control strategies observed when healthy young adults experience a more threatening condition resemble specific components of those used by fearful elderly or individuals with PD. Fear of falling may influence only specific components of postural control strategies that may be identified and treated.

The thesis also provides the first known exploration of the prevalence of fear of falling or low balance confidence and its impact on the control of posture in PD. Fear of falling was prevalent in individuals with PD and this fear was highly related to disease severity. Furthermore, the impact of fear of falling on postural control was revealed in the differences in postural sway between more confident and less confident groups of PD patients. For those who were less confident for performing ADLs, greater disease severity and also greater postural sway were observed compared to those who were less fearful. The variation in balance performance could be further explained through the addition of balance confidence information to information concerning disease severity. The results of this study provide insight into the development of the balance efficacy postural control model; in particular, the interactions between psychological (balance confidence) and physiological (disease severity) factors and their impact on the control of posture. Furthermore, actual and perceived changes in postural control may lead to a restriction of activities in this population, an area of research that may provide interesting insight into behavioural modifications in this population.

King et al. (1998) summarized research focusing on the design of physical activity interventions to improve health and quality of life for older adults. These interventions are critical due to the activity limitation prevalent in the elderly (Moore et al. 1999). Exercise has been shown to improve balance and mobility as well as decrease the risk for falls (Shumway-Cook et al. 1997). However, a combination of exercises focusing on balance and mobility as well as targeting balance confidence may provide significant benefit to the elderly and individuals with balance disorders. Balance efficacy appears to be the one factor in the balance efficacy postural control model that is most likely to influence the outcome measure, risk for falls, and is recommended as a target for intervention (Baumann 1999; King and Tinetti 1995; Tinetti et al. 1994). Furthermore, efficacy appears to be significantly associated with perceived disability independent of actual underlying physical abilities (Seeman et al. 1999), is modifiable and has been targeted in a number of different health-related behaviours (Maddux 1995, McAuley and Blissmer 2000; McAuley et al. 1993). A treatment intervention targeting fear of falling has been reported recently and suggests that older adults who received treatment for their fear of falling or low balance confidence showed increased levels of activity and improved mobility (Tennstedt et al. 1998). The results from all three studies in this thesis provide information and evidence that balance confidence must be considered when examining postural control in elderly and patients with balance disorders. The evidence that balance confidence modifies postural control on different postural tasks suggests that confidence can influence a host of daily activities in which individuals may engage.

FUTURE DIRECTION

The major finding of this body of work is that the control of posture is influenced by balance confidence, emphasizing the importance of identifying both psychological and physiological influences on postural control. The understanding of how psychological factors modify postural control is critical for balance assessment and fall prevention strategies in the elderly and individuals with balance disorders and can also provide valuable information for the design of successful treatment interventions for individuals who are fearful of falling.

Research examining the role of fear on postural control and falls is made more difficult due to the varied definitions of "fear" and its measurement and the complex interactions of different psychological and physiological responses to a threat to posture. The thesis highlights the need for future research to elucidate the precise role of balance efficacy on the control of posture and ultimately the association of both of these entities in populations at risk for falls. Cooperation between researchers focusing on social-cognitive theory and its effects on behaviour and researchers specializing in the understanding of postural control will provide better outcomes for assessment and intervention strategies that can reduce the risk for falls in the elderly and individuals with balance disorders. Targeting interventions toward improving balance efficacy in older adults and individuals with balance disorders may provide for increased mobility and limit activity restriction in these populations. Recently, studies have been conducted to treat "fear of falling"; however this area of research is in its infancy and needs direction. For these interventions to provide help and be successful, targeting the correct areas for treatment are critical. Thus, understanding of social-cognitive theory and its interaction and effect on balance performance and the ultimate outcome, risk of falls, is essential.

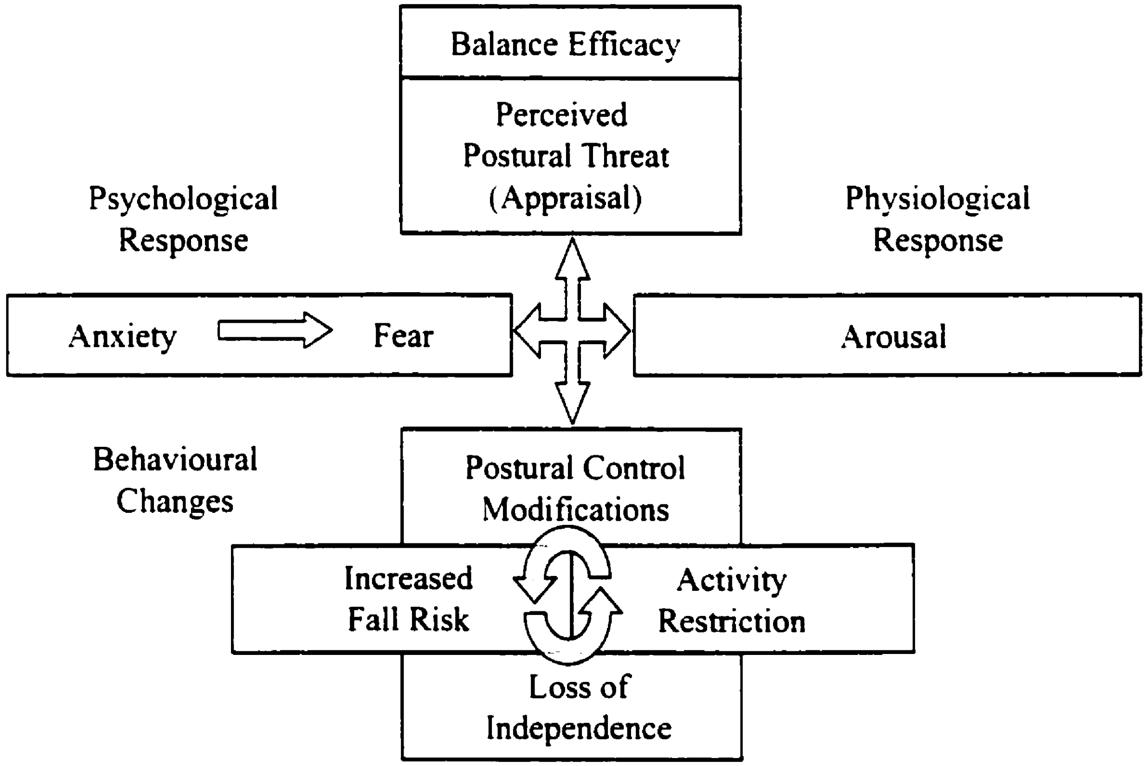

Figure 5.1. Proposed balance efficacy postural control model to illustrate the effects of balance efficacy on postural threat appraisal and the associated behavioural modifications that result from this interaction.

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APPENDIX

Perceived Anxiety Questionnaire

Please answer the following questions about how you honestly feel just after performing the balance test at this height using the following scale:

1	2	3	4	5	6	7	8	9
I did not feel this at all				I felt this moderately				I felt this extremely

1. I felt nervous
2. I had lapses of concentration
3. I had self doubts
4. I felt myself tense and shaking
5. I was concerned about being unable to concentrate
6. I was concerned about doing the balance task correctly
7. My body was tense
8. I had difficulty focusing on what I had to do
9. I was worried about my personal safety
10. I felt my stomach sinking
11. While doing the balance task, I did not pay attention to the point on the wall all of the time
12. My heart was racing
13. Thoughts of falling interfered with my concentration
14. I was concerned that others would be disappointed with my balance performance
15. I found myself hyperventilating
16. I found myself thinking about things not related to doing the balance task