THE EFFECT OF ANXIETY ON MOTOR LEARNING DURING A POSTURAL TASK

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Dedication

This thesis is dedicated to Amber, Megan, and Benjamin.

Thank you.

Abstract

The effect of anxiety on motor learning during a balance relevant task was investigated. Twenty participants (mean age 22.0 ± 2.7 years) were randomly divided into groups that completed the task whilst standing directly on the platform or on 9cm high pedestals, thus constructing Non-Anxious (NA) or Anxious (A) environments. Participants trained for 36 trials in a continuous, pseudo-random oscillating balance task consisting of pseudo-random amplitude translation at 0.5Hz for 45 seconds each on Day 1 and returned for Retention and Transfer tests on Day 2. Motor performance was impaired by training in an anxious environment and this effect persisted across retesting in both non-anxious and anxious environments. Anxiety also tended to further impair transfer of motor performance improvements to a non-anxious environment. These findings have implications for the success of balance training programs in patients who are anxious or afraid of falling.

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List of Abbreviations

A.....Anxious

A-P.....Anterior-Posterior

Aq.....Acquisition

ACT.....Attentional Control Theory

BOS.....Base of Support

CNS.....Central Nervous System

COM.....Center of Mass

COP.....Center of Pressure

DRP.....Discrete estimate of Relative Phase

GRFV.....Ground Reaction Force Vector

GSC.....Galvanic Skin Conductance

Hz.....Hertz

IC.....Instantaneous Coupling

MAA.....Mean Absolute Amplitude

NA.....Non-Anxious

RM-ANOVA.....Repeated Measures Analysis of Variance

R.....Retention

S.....Siemens

T.....Transfer

Tr.....Trained

Chapter 1: Introduction

Humans interact and navigate within their environment through the use of sensory and motor systems that are directed by the Central Nervous System (CNS) (Peterka, 2002). The sensory system informs the CNS about the position and configuration of the body with respect to the current environmental context within which movement is performed. The CNS interprets the incoming sensory information and formulates a series of contextually appropriate motor commands that are transported along the neural system to control muscles that are relevant to the desired movement outcome. A fundamental task that underlies successful environmental interaction is maintenance of balance, which is involved in a myriad of functional motor tasks.

As individuals age, the ability to maintain balance becomes increasingly difficult. The natural aging process results in muscle loss which contributes to weakness and an inability to adequately respond to motor challenges (De Rekeneire et al., 2003; Pijnappels, van der Burg, Reeves, & van Dieen, 2008). Aging also contributes to sensory degeneration such as reduction of vision acuity and loss of proprioceptive sensitivity, thus resulting in poor sensory feedback. Together, these factors contribute to an increased fall risk (Lord, 2006; Lord, Clark, & Webster, 1991). Deterioration of cognitive processing and a reduction in attentional resources further reduces the efficacy of the CNS with respect to balance challenges (Huxhold, Li, Schmiedek, & Lindenberger, 2006; Jamet, Deviterne, Gauchard, Vancon, & Perrin, 2007). As a result, the natural aging process decreases the ability to maintain balance and contributes to an increased risk of falling. As a result, almost one third of people over the age of 65 fall each year (O'Loughlin, Robitaille, Boivin, & Suissa, 1993) and falls are the leading cause of death from injury for this population (Sattin, 2002). Some of the physical effects of falling are soft tissue damage, broken bones, loss of function, and death (Astrid, Anne Marie, & Knut, 2000; Herman, Giladi, Gurevich, & Hausdorff, 2005; Lajoie & Gallagher, 2004; Laughton et al., 2003; Pijnappels, et al., 2008; Shumway-Cook et al., 2009). Approximately 1 in 25 people who are in a nursing home will break their hip or suffer another type of fracture and 1 in 5 will suffer a head injury each year as a result of a fall (Lauritzen, 1996; Nurmi, Lüthje, & Kataja, 2004; Quigley et al., 2011). With all things considered, elderly people who fall have a lower survival rate than their non-falling companions (Nurmi, et al., 2004).

Although the physical effects of falling can be devastating and intrusive, the psychological outcomes of falls are further debilitating and often outlast the physical injuries. The foremost psychological effect of a fall episode is the development of a fear of falling (Jørstad, Hauer, Becker, & Lamb, 2005). Fear of falling is defined as a "lasting concern about falling that leads to an individual avoiding activities that he/she remains capable of performing" (Tinetti & Powell, 1993, p. 36). Fear of falling can manifest without ever experiencing a fall (Brouwer, Walker, Rydahl, & Culham, 2003). The effects of fear of falling often lead to withdrawal from activity, reduced self-confidence, depression, and anxiety about falling (Maki, Holliday, & Topper, 1991). These physical restrictions contribute to further muscle weakness and reduced physical coordination while the psychological ramifications, including anxiety about falling, results in reinforcement of the fear and lower balance confidence. Together, these physical and psychological conditions precipitate a self propelling negative spiral of a greater fear of falling, further withdrawal from activity, and further increased risk of falling (Scheffer, Schuurmans, van Dijk, van der Hooft, & de Rooij, 2008). Individuals with a fear of falling report lower quality of life scores, even if they have not previously experienced a traumatic fall (Scheffer, et al., 2008). Furthermore, anxiety and trepidation about a fall possibility are reportedly amplified among those who have a fear of falling when fall possibility increases (Maki, et al., 1991). Anxiety about falling, whether due to a general fear or imposed by a situational construct, has been known to compromise successful performance of fall-avoidant strategies (Adkin, Frank, Carpenter, & Peysar, 2002) and could contribute to the increased fall episodes observed in the elderly (Cumming, Salkeld, Thomas, & Szonyi, 2000).

The impact of a fall episode extends beyond the immediate consequences to the individual faller. Fall episodes also place a tremendous burden on those who help the injured, such as loving caregivers (Kuzuya et al., 2006). Further resources are demanded from the health care systems that provide acute and long term treatment as well as rehabilitation facilities and healthcare follow up. The cost of treatment and rehabilitation as a result of falls amongst the elderly exceeds $19 billion each year in North America alone (Stevens, Corso, Finkelstein, & Miller, 2006) and is expected to exceed $43 billion by the year 2020 (Stevens & Sogolow, 2005).

Reducing the number of falls in the elderly has great benefit for the individuals, their caregivers, the health care systems, and the economy. A number of programs have been developed in this effort and include both proactive and post-fall interventions. Most commonly employed programs include risk and environmental assessments (Pighills, Torgerson, Sheldon, Drummond, & Bland, 2011), exercise interventions (Carter, Kannus, & Khan, 2001), balance training programs (Mansfield, Peters, Liu, & Maki, 2010), or a combination of these three. Environmental assessments and interventions identify and reduce environmental hazards such as loose rugs or mats, slippery floors, obstacles, and trailing cords (Sattin, Rodriguez, DeVito, & Wingo, 1998) while exercise interventions promote muscle building leading to increases in strength. Balance training is comprehensive training that normally includes basic fitness and exercise components as well as specific anti-fall related exercises such as practice in grasping hand holds or stepping successfully over an obstacle, all of which are intended to improve confidence, mobility and function (Skelton & Dinan, 1999; Steadman, Donaldson, & Kalra, 2003).

Numerous studies have demonstrated that a combination of environmental assessments, exercise, and balance training are an effective way to reduce falls and fall risk. For instance, a recent pilot study found that elderly patients who challenged their balance daily by doing activities such as practicing to step over objects resulted in a significant reduction in falls and an increase in balance confidence (Clemson et al., 2010). In another study, clinical measures of fall risk improved when participants engaged in a multicomponent exercise program of weight-bearing exercises, balance training, and posture correction training three times per week for nearly a year (Park, Kim, Komatsu, Park, & Mutoh, 2008). Additional studies have reported that balance training and exercise are effective for increasing confidence during walking (Steadman, et al., 2003) and have demonstrated an improvement of clinically relevant indicators of balance capacity such as standing with eyes closed, and standing on one leg while shaking the head (Ledin, Kronhed, Möller, & Möller, 1990; Seidler & Martin, 1997). Further support of such training programs can be found within the literature, and training in anti-fall related balance tasks is regarded as a viable intervention for reducing the risk of falling amongst the elderly (Granacher, Muehlbauer, Gollhofer, Kressig, & Zahner, 2010; Nagy et al., 2007; Sauvage et al., 1992; Seidler & Martin, 1997; Steadman, et al., 2003).

Balance training is administered with intent to improve coordination between the sensory and motor systems, thereby facilitating the possibility for effective response when challenges are encountered in the environment. Through balance training, individuals are introduced to motor strategies that serve to maintain successful posture in demanding environments. A fundamental principle of such balance training programs is to provide an opportunity to learn fall related counter-manoeuvres that are relevant and appropriate to the demands imposed by the environment. For instance, in one study, elderly subjects practiced balance recovery by taking a step or grasping a railing in response to a postural disturbance that was generated from a platform that moved unpredictably (Mansfield, et al., 2010). Practice of these balance recovery manoeuvres resulted in a grasping response that was quicker and subjects took fewer steps in response to postural disturbances. In order to extend these findings into other related but non-specific real-world balance improvements, recent studies have demonstrated that older adults can acquire general movement strategies that optimize balance in motor tasks that are more similar to real-world conditions (Karen Van Ooteghem, Frank, Allard, & Horak, 2010), a finding that lends its support to current training paradigms.

Unfortunately, fear and anxiety are also known to interfere with motor performance outcomes (Brown, Polych, & Doan, 2006; Pijpers, 2006; Pijpers, Oudejans, Holsheimer, & Bakker, 2003). For instance, individuals standing on the edge of a platform adopt a conservative posture characterized by reduced postural sway and leaning away from the edge of the platform (Brown, Polych, et al., 2006), while conservative strategies during walking on a raised walkway include a reduction in walking speed and shorter steps (Brown, Gage, Polych, Sleik, & Winder, 2002). Though these automatic strategies most often result in protective behaviours, or adaptations, that could help reduce the possibility or severity of a fall, there is a possibility that motor adaptations which are applied excessively or out of context could result in reduced or impaired performance. Delbaere and colleagues (2009) reported that individuals who were afraid of falling decreased their walking speed disproportionately in comparison to those who were not afraid. The authors suggest that this adaptation was sub-optimal and could contribute to decreased walking stability. Thus, in line with an inverted U performance curve, conservative strategies that are applied appropriately may reduce fall risk but could contribute to increased fall risk if applied excessively.

The goal of balance training in the fall fearful population is to stimulate motor learning of balance appropriate skills in order to increase motor performance when faced with a postural challenge. Although the effect of anxiety on performance and acquisition of simple motor tasks has been well characterized, the effect of anxiety on motor learning during a balance specific task has been altogether ignored. The literature is sparse on the effects of anxiety on motor learning. There have, however, been a handful of studies that have attempted to address this problem. For instance, Calvo & Ramos (1989) observed that when stressed, individuals who were naturally anxious took longer to assemble a puzzle while reciting numbers backwards than did their non-anxious counterparts, even with practice. The authors of this study concluded that anxiety negatively affected motor learning, but only in highly demanding tasks that require attention. More recently, Oudejans and colleagues (2009; 2010) speculated that practice in an anxious environment may result in motor adaptations that can negate the effect of anxiety. Subjects who practiced a basketball free throw while in an anxious environment performed equally as well when retested in the same anxious environment. The subjects who trained in the non-anxious environment, however, demonstrated a performance decrement when retested in the anxious environment. In this case, the authors concluded that motor learning in an anxious environment can result in self-regulatory adaptations and modulated motor strategies that may improve motor performance in conditions that cause anxiety.

Eysenck and Calvo's Attentional Control Theory (ACT) provides a suitable framework in which to explore the effect of anxiety on postural control (2007). The ACT postulates that anxiety increases the amount attention directed on the threat-related stimuli and reduces the amount of attention directed on the goal of the task. For example, there are many reports of car accidents that have been caused by a distraction from a bee or other insect that has flown into an open car window, whereby attention has been directed at the insect rather than at the safe control of the vehicle. In extending this analogy to parallel postural control, previous work in our lab has confirmed that elderly who fear falling attend more to fall related stimuli than neutral stimuli (Brown, White, Doan, & de Bruin, 2011). These findings imply that individuals who are afraid of falling are more likely to pay attention to a fall-threatening stimulus, such as an icy patch on a sidewalk, than to controlling their posture. Just like the car accident victim who has focused on the bee rather than safe vehicular control, individuals who are afraid of falling may focus on the threat rather than effective postural control, resulting in an increased risk of falling.

Finally, it has been established that both motor learning (Lam, 2008) and postural control (Shumway-Cook & Woollacott, 2000; Woollacott & Shumway-Cook, 2002) require attention. Given that attentional resources are finite, the findings that individuals allocate increased attention to anxious stimuli means that in these cases, less attention is available for learning the motor task. As a result, in situations where attention is limited or the attentional demands of the learning task are higher, learning could be compromised. Indeed, the ACT predicts that the presence of anxiety will impair motor learning by directing attention towards the threat and away from learning the postural task at hand.

1.1 Purpose of the Study

The purpose of my thesis was to determine whether anxiety about falling compromises motor learning of a balance relevant task.

1.2 Rationale

The positive effect of balance training on reducing falls in the elderly has been established. Anxiety about falling, a characteristic of an acquired fear of falling, is known to negatively affect motor behavior. The effect of anxiety on motor learning is yet to be established but according to the ACT motor learning should be impaired in the presence of anxiety. As a result, the possibility remains that the true potential of balance training programs may be compromised by the psychological presence of fear of falling as well as transient anxiety brought about by novel training environments. To this end, further study is warranted to determine the effect of anxiety about falling on the capacity to learn and apply balance related strategies for use in posturally compromising contexts.

1.3 Significance

This knowledge will provide the first step toward understanding whether balance training protocols are compromised by anxiety about falling. This knowledge is important because it is necessary to provide effective and efficient training programs that serve to increase patient benefit and reduce cost burden. This information will assist clinicians in identifying and providing optimal proactive and post-fall training programs that account for, recognize and treat psychological state in order to increase training efficiency.

1.4 Hypotheses

Motor learning of a balance relevant task will be compromised by the presence anxiety. As such:

a) Motor performance during skill Acquisition will be reduced in conditions of increased anxiety about posture.
b) Retention of motor performance improvements that were acquired during conditions of increased anxiety about posture will be reduced.
c) Transfer of motor performance improvements to non-anxious conditions will be reduced if they were acquired during conditions of increased anxiety about posture.

1.5 Limitations

A limitation of this present study is that the subjects were a cohort of younger adults who reported no fear about falling. Although older adults are just as capable of generalized motor learning in postural tasks (Van Ooteghem, et al., 2010), the possibility remains that older adults, and in particular those who fear falling, could be differentially affected by the presence of anxiety during motor learning. Studies within the target population may be necessary to fully describe the relationship between motor learning and anxiety in the elderly.

Chapter 2: Review of the Literature

2.1 Human Postural Control

2.1.1. Fundamentals of postural control. The process of maintaining balance whilst standing is known as postural control. Failure of the CNS to fulfill the function demanded of the task to provide environmentally appropriate motor output necessary to maintain balance can lead to instability and fall episodes. Falling is the physical outcome of failure of the CNS to appropriately control balance and efforts to reduce the possible negative consequences of falling depend on a succinct understanding of human postural control.

Successful postural control requires explicit knowledge and information about how the body is interacting with the environment and its surroundings. Feedback for postural control in humans is primarily provided by three specialized sensory systems: (1) the somatosensory system, (2) the vestibular system, and (3) the visual system. The somatosensory system includes the cutaneous receptors on the sole of the foot that provide feedback about the tactile properties of the external surface, as well as muscle spindles, joint receptors, and Golgi organs that provide information about forces related to the task and position of the body segments with respect to each other (Alexander, 1994). Degeneration of the somatosensory system can lead to impaired position sense and reduced pressure sensitivity, resulting in poor information about how the body is configured with respect to the support surface, thus increasing fall risk (Horak, Nashner, & Diener, 1990; Woollacott & Shumway-Cook, 1990). A degradation of the somatosensory system is common with aging and is a complication of diabetes in the form of diabetic neuropathy (Horak, Dickstein, & Peterka, 2002).

The vestibular system includes the semicircular canal system and the otolith structures, both located in the inner ear, which respectively provide feedback about the rotational and linear accelerations of the head. Damage of the vestibular system can lead to dizziness, vertigo, and an inability to maintain balance (Buchanan & Horak, 2002; Horak, Shupert, & Mirka, 1989; Mergner, Maurer, & Peterka, 2002). The visual system includes the eyes and provides information about the position of head in relation to its surroundings, as well as identifies obstacles and challenges in the environment. A reduction in visual acuity is common in old age and can increase fall risk. As other sensory systems degenerate, older adults often try to compensate by depending to a greater extent on visual feedback, resulting in increased fall risk when vision systems are compromised and environmental hazards are difficult to distinguish (Lord, 2006; Wade, Lindquist, Taylor, & Treat-Jacobson, 1995). Acute and significant damage or degeneration of postural sensory systems can cause difficulties in maintaining balance, thereby increasing fall risk. Small and insignificant degenerations that are associated with healthy aging, however, are usually compensated by relying to a greater extent on other, more accurate or less degenerated sensory systems.

In an effort to describe and understand the mechanics of postural control, the mechanical attributes of bipedal standing have been modeled as a multilink inverted pendulum whereby the feet are fixed at the origin of the pendulum and the head is the bob (Cleeremans & McClelland, 1991; Corna, Tarantola, Nardone, Giordano, & Schieppati, 1999; Maki & McIlroy, 1996; Winter, 1995; Winter, Patla, Prince, Ishac, &

Gielo-Perczak, 1998). The center of mass of all segments in this multi-link pendulum model are summed to provide an aggregate location of the whole body center of mass (COM) (Winter, 2009). During upright stance the spatial location of the COM is naturally dynamic, oscillating at a rate of 0.45 Hz (Loram, Maganaris, & Lakie, 2005). This natural oscillation, known as spontaneous postural sway, is due to physiological processes such as respiration (Jeong, 1991) , efforts to maintain appropriate muscle tone that ensures corrective action to counteract the effects of gravity (Winter, 1995), and exploratory mechanisms to ascertain whether input from the multiple sensory systems has remained reliable (Carpenter, Murnaghan, & Inglis, 2010).

Stability during bipedal standing requires that the horizontal position of the COM remain within the vertical projection of the area circumscribed by the feet or base of support (BOS; Figure 2.1) (Horstmann & Dietz, 1990). In the absence of any compensatory adjustments, excursions of the COM beyond the prescribed limits of the BOS will compromise stability and cause a fall to occur. To ensure that balance is preserved, the CNS provides motor adjustments in anticipation of (Laessoe & Voigt, 2008; Morasso & Sanguineti, 2002; Noe, Quaine, & Martin, 2004) or response to (Bötzel, Feise, Kolev, Krafczyk, & Brandt, 2001; Greenwood & Hopkins, 1976; McIlroy & Maki, 1993; Moore, Rushmer, Windus, & Nashner, 1988) COM excursions. For instance, when subjects know that a perturbation to balance is about to occur, they will actively adjust their COM to a position that is more favorable in minimizing the consequences of the disturbance (Laessoe & Voigt, 2008) and when exposed to an unpredictable perturbation the corrective motor response is observed starting about 73 – 100ms after the initial perturbation (Horak & Nashner, 1986).

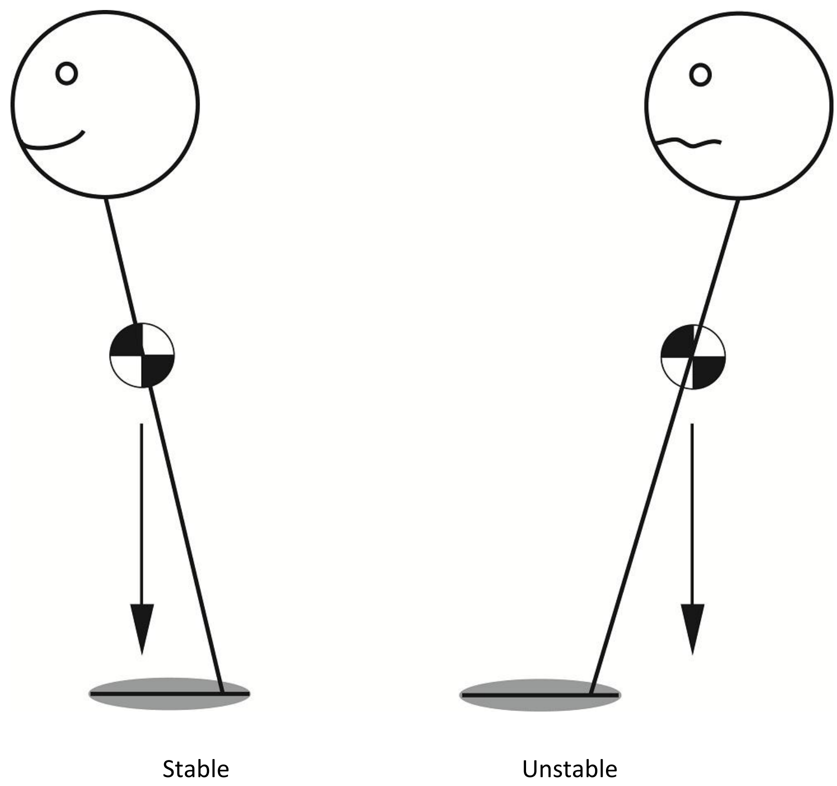

Figure 2.1 Postural stability depends on the vertical alignment of COM (cross-hatched circle) over the BOS (grey ellipse). If the COM maintains vertical alignment with the BOS, posture is stable. If the COM fails to maintain vertical alignment with the BOS, posture is unstable and a fall is likely to occur unless corrective action is taken.

Although barely perceptible to the naked eye, the trajectory and characteristics of postural sway provides valuable insight into the capacity of the CNS to control and regulate balance. To further investigate the resultant motion and forces related to postural control and sway, practitioners use motion and force capture technologies such as video cameras and force platform systems to record this slight movement. Motion tracking technologies capture a digital representation of body position in space while force platforms record the forces applied to the body from the support surface. Motion tracking technologies serve to record the three dimensional coordinates of specific body landmarks during movement. The outcome of this process provides a digital three-dimensional reconstruction of the body as it moves through a calibrated volume of space. Similarly, the resultant ground reaction forces can be recorded in a standing subject using a force platform (Nashner, 1983). These forces are produced as a result of the corrective actions exercised by the motor control system in order to keep the COM in a posturally stable position. These forces are detected by the force platform and used to construct a single ground reaction force vector (GRFV). The direction and origin of the GRFV changes in direct accordance with the fluctuations in force output required to counteract external disruptions and with the natural, spontaneous sway of the body (Figure 2.2). The origin of the GRFV is termed the center of pressure (COP), and is derived from the calculated moment arms in the horizontal plane from the recorded gravitational forces and moments, described in equation 1.

Equation 1: $COPx = My/Fz$ *and* $COPy = Mx/Fz$, *where COPx and COPy are the coordinates of the origin of the GRFV, My and Mx are moments along the x and y axis respectively, and Fz is the vertical gravitational force.*

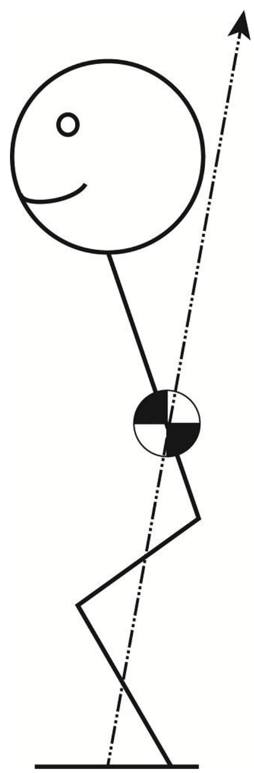

Figure 2.2 The Ground Reaction Force Vector (GRFV; dashed arrow) represents the origin, direction, and magnitude of the sum of all forces acting on the body from the ground. The origin of the GRFV is COP.

Techniques of COM and COP quantification have varied extensively over the past decades but the most current approach includes analysis and interpretation of the amplitude and frequency characteristics of the movement (Dault, de Haart, Geurts, Arts, & Nienhuis, 2003; Hasan et al., 1996; Winter, et al., 1998). Such measures include the area traversed by the COP during a trial, often characterized as an elliptical sway area, velocity of the COP or COM, or the path length of the COP. These measures can be used to compare the dynamics of the COP or COM and are interpreted to indicate the capacity to proactively and reactively control posture and prevent a fall episode.

In addition to measures that assess the dynamics of the COM or COP, joint coordination patterns and dynamic postural responses and can be investigated by comparing the dynamic movement between specific body locations or joints. Movement can be quantified in relation to the static environment, a dynamic aspect of the task such as a perturbation or translation sequence, or compared to other joints or landmarks. Quantification of coordination patterns can be accomplished by comparing the correlation of movement or relative timing between two of landmarks, joints, or other reference point. Motor performance, and in particular, the ability to minimize the effect of a postural disruption, can also be assessed with respect to the environment by measuring the observed magnitude of disturbances in response to perturbation or translation sequence.

2.1.2. Behavioral adaptation and central motor programming. To better understand the response mechanisms that are produced and controlled by the CNS and executed by the motor control system, situations of balance challenge have been simulated in the laboratory environment. Over the past few decades researchers have employed transient and continuous disruptions and challenges to the neuromotor system through external or internal sources. External disruptions are commonly administered as disturbances to balance in the form of a push or pull to the body or by shifting the support surface on which the individual is standing (Brown, Jensen, Korff, & Woollacott, 2001; Horak, Henry, & Shumway-Cook, 1997; Horak & Nashner, 1986; Maki & Ostrovski, 1993), while internal disruptions are created by self-generated balance perturbations such as intentional arm swinging or rocking motions (Noe, et al., 2004; Stelmach, Zelaznik, & Lowe, 1990).

From this invested line of research, we now know that individuals respond to external disturbances using characteristic behavioral patterns (Horak & Nashner, 1986), but are able to adapt and modify that behavior based on, among other things, the perceived threat to balance and the physical constraints of the environment (Adkin, Campbell, Chua, & Carpenter, 2008; Brown & Frank, 1997; Marigold & Patla, 2002; Nashner, 1976; Rankin, Woollacott, Shumway-Cook, & Brown, 2000). In real world settings, individuals must maintain postural control across a wide variety of environmental challenges, an outcome that depends upon the integration of anticipatory and reactive responses. Early work by Horak and Nasher (1986) investigated whether behavioural responses progressed differently depending on the constraints of the environment. Individuals were exposed to repeated perturbations while standing on a platform that was either longer or shorter than the length of the feet. Subjects initially responded in the same way to each perturbation on the different support surfaces but after 5 – 15 trials, differing motor responses were observed. The authors interpreted these results to suggest that subjects first produced a generic, or generalized motor response that was subsequently modified to the specifics of the task. This initial utilization of general patterned responses and subsequent divergence to an optimal strategy provides an explanation for capabilities of rapid motor response based on prior experiences that can be subsequently fine-tuned for the specifics of the task and environment over time.

2.1.3. Adaptive postural strategies. In an effort to maintain postural control over a wide range of environmental contexts, two distinct postural strategies have been observed: the ankle strategy and the hip strategy. The ankle strategy exploits the properties of the "inverted pendulum" and postural adjustments originate at the origin of the pendulum, that is, at the ankles. It is characterized by distal to proximal leg to hip muscle activation, thus resulting in rotation about the ankles while the rest of the body maintains a rigid form (Horak & Nashner, 1986). Due to the relatively large moment and, by extension, muscle torque of the leg needed to effect postural position, this strategy is optimized for perturbations induced as light disturbance to COM position (McCollum & Leen, 1989), such as when the oscillation frequency is below the normal sway frequency (Buchanan & Horak, 1999).

The hip strategy, in contrast, depends on rapid relocation of the COM over the BOS brought about by reconfiguration of the body segments in which hip decoupling allows the trunk to fold into pike arrangement. In contrast to the ankle strategy, the hip strategy is achieved by proximal to distal hip to leg muscle activation and causes rapid linear posterior or anterior translation of the hips. The hip strategy is capable to respond to postural disturbances that are fast and have significantly large amplitude (Runge, Shupert, Horak, & Zajac, 1999). In cases where postural corrections that utilize the ankle or hip strategy are unable to sufficiently modify the location of the COM in order to prevent an excursion outside the BOS, individuals can also respond by taking a step or grasping a support. This strategy alters the BOS so that it is larger and in a more favourable position with respect to the COM (Maki & McIlroy, 1997), thus more likely to prevent a fall (Figure 2.3).

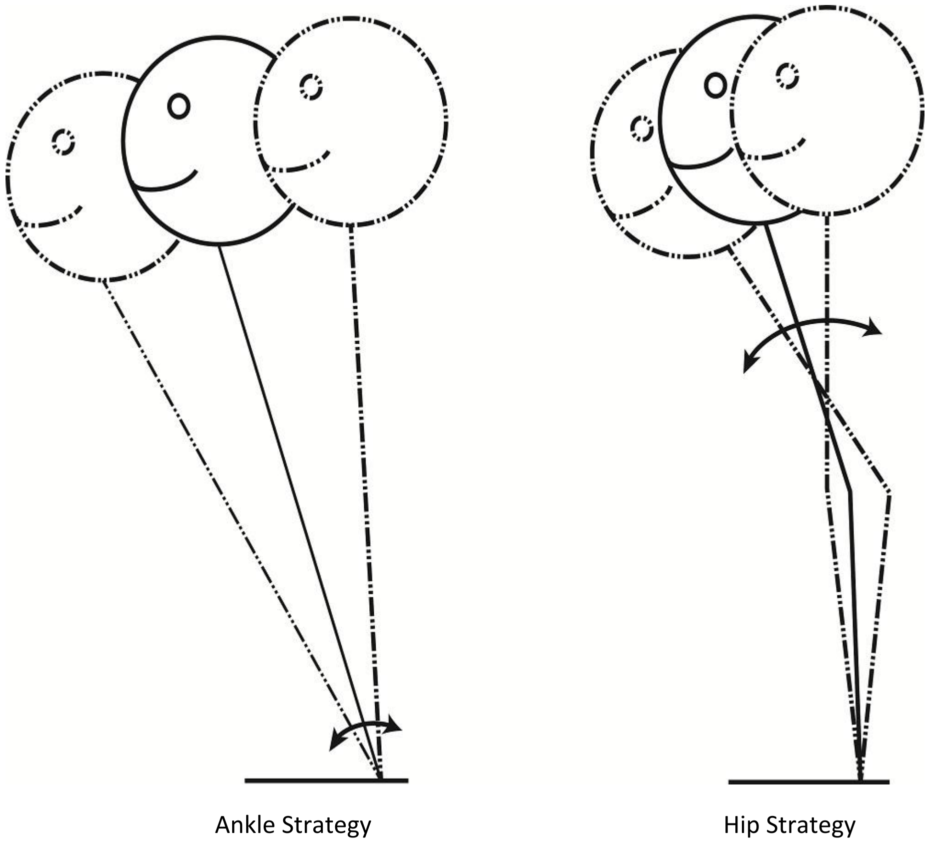

Figure 2.3 The ankle strategy of postural control is characterized by a rigid body form and rotation about the ankles. Conversely, the hip strategy relies on rapid translation of the hips, resulting in hip decoupling and a pike configuration.

2.1.4. Postural Control for Oscillating Sequences. In line with the inverted pendulum model of human stance, postural corrections that utilize an ankle strategy are effective when perturbations are slow, that is, for frequencies up to 0.5Hz (McCollum & Leen, 1989). Above 0.5Hz, a change towards a hip strategy is necessary which requires a decoupling of the hip and an introduction of multiple degrees of freedom. Investigation into the postural responses that result from continuous oscillating perturbations has revealed that the frequency of the oscillating postural task also results in distinct movement patterns.

Ko and colleagues (2001) have described four distinct movement patterns that occur as a function of translation frequency. The "rigid mode", ideally suited for slow frequencies < 0.19Hz, is characterized by stiffening of the ankle, knee, and hip joints such that the body acts as a one rigid segment. In this movement pattern, the landmarks of the body remain directly vertical to the translating platform and the body moves backwards and forwards with the platform, resulting in head and upper body movement that is coupled and proportionate to the translation sequence. In the "ankle mode", which normally occurs for frequencies around 0.5Hz, the knee and hip joints remain rigid while the body adopts a distinct inverted pendulum motion by oscillating at the ankles. The oscillation of the ankles introduces a single degree of freedom and head motion is significantly reduced in comparison to the rigid mode as a result of the ankle motion, resulting in a characteristic "head-in-place" movement pattern.

When the frequency of the postural translation increases further (>0.9Hz), postural control is achieved by introducing increasing degrees of freedom at the hip first (ankle-hip mode) and then at the knee (ankle-knee-hip mode) for even faster translation frequencies. In these modes, motion of the head with respect to the environment is still reduced in comparison to the rigid mode, but increased oscillation at the hip and knee are also observed (Figure 2.4).

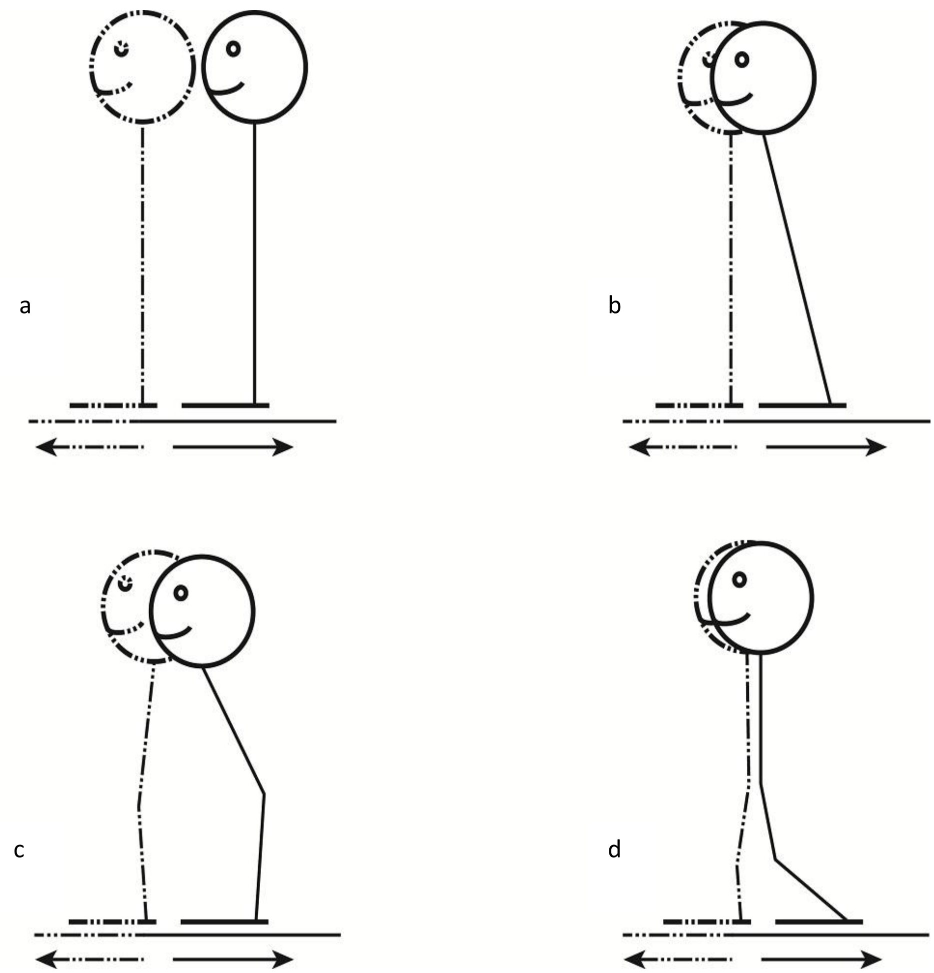

Figure 2.4 Four frequency dependent postural strategies are associated with oscillating postural translation. (a) The "rigid mode" is characterized by a stiff body that moves as one segment. (b) The "ankle mode" is characterized by rotation at the ankle that counteracts the translation sequence. (c) The "ankle-hip mode" is characterized by negatively correlated movement at the ankle and the hip. The knee joint remains rigid. (d) The "ankle-knee-hip mode" is characterized by freedom of movement in the ankle, knee, and hip joints. Adapted from Ko and colleagues (2001)

2.2 Cognitive Contributions to Postural Control

2.2.1. Central set and postural control. Based on documented evidence, it is now known that the CNS modifies motor output according to the demands of the environment as well as how those demands are perceived (Horak, Diener, & Nashner, 1989). This outcome, known as the Principle of Central Set, has been implicated to provide an explanation for the relationship between initial external demands and motor outcomes. The Principle of Central Set postulates that initial motor output for a task is determined by prior exposure to that task (Winstein, Horak, & Fisher, 2000). For example, individuals will establish a gripping force for an object prior to lifting it based on assumed knowledge about its mass or tactile properties from previous experience with similar objects (Cole, Rotella, & Harper, 1999; Winstein, et al., 2000). Within postural control, the Principle of Central Set is used when an individual acts conservatively or leans away from the edge when standing at the edge of a cliff since it is perceived to be posturally threatening and of high consequence if they were to fall. As such, motor patterns are adapted to different environmental context based on their perceived threat and the psychological state of the individual. In efforts to better understand the Principle of Central Set, a significant amount of research over the last two decades has been dedicated to examining the possible variables that mediate the relationship between psychological state and motor output. A key finding to emerge from this extensive line of inquiry is that the psychological state of anxiety, as imposed by a balance challenge or a threatening environment can directly influence the motor control of balance.

2.2.2. The postural threat paradigm. Brown and Frank (1997) first documented the influence of psychological state alone on postural control in an experimental manipulation where subjects stood on a platform that could be elevated to 1.3m beyond ground height. Given that the potential consequences associated with a fall episode were greatest in the highest platform height, this manipulation provided opportunity to explore the postural adjustments associated with threatening environmental contexts. In this way, Brown and Frank compared postural adaptation and recovery in a low threat context (ground level) against a posturally threatening context (high threat context). In the posturally threatening context, subjects adopted a proactive or anticipatory rearward lean that contributed to a more posterior COM position, in other words, an instinctive "shying away from the edge" behavior. The authors interpreted this behavior as a motor adaption that occurred in response to the increase in postural anxiety.

This manipulation of environmental context to impose a threat to balance and heighten anxiety about falling is known as the postural threat paradigm and since the work of Brown and Frank (1997), has provided the foundation for a significant body of research. This paradigm has been employed to explore how a posturally threatening context results in motor adaptations in tasks of standing (Adkin, Frank, Carpenter, & Peysar, 2000; Brown, Polych, et al., 2006; Carpenter, Frank, Silcher, & Peysar, 2001), postural disturbances (Adkin, et al., 2008; Adkin, et al., 2002; Brown & Frank, 1997; Carpenter, Frank, Adkin, Paton, & Allum, 2004), steady state gait (Brown, et al., 2002; Gage, Sleik, Polych, McKenzie, & Brown, 2003), obstacle negotiation (Brown, Doan, McKenzie, & Cooper, 2006; McKenzie & Brown, 2004), and complex movements such as rock climbing (Pijpers, Oudejans, & Bakker, 2005). Moreover, use of the postural threat paradigm has also provided invaluable insight in how anxiety about falling affects people with Parkinson's disease (Adkin, Frank, & Jog, 2003) and the elderly (Brown, et al., 2002; Brown, Doan, et al., 2006; Gage, et al., 2003).

Along this line of inquiry, Carpenter and colleagues (2001) explored the mechanism of the observed motor adaptations. They observed that when in an anxious condition, subjects leaned away from the edge of the platform as indicated by traces of the COM and COP. Furthermore, they reported an increase in activation in the muscles that are required for postural control, thus contributing to an increase in stiffness. Postural adaptation in response to anxiety about posture has also been observed in response perturbations that were applied in multiple directions. Subjects who experienced a postural disturbance of a multidirectional rotation about the ankles in an anxious condition demonstrated increased amplitude in postural muscle responses accompanied by reduced displacement of their COM and smaller angular displacement of trunk and pelvic body segments (Carpenter, et al., 2004). These findings confirm that motor adaptations as a result of anxiety are not limited to static or one-dimensional tasks.

In continuing research about the effects of anxiety about falling in postural tasks, Adkin and colleagues (2002) explored whether motor adaptations occurred when perturbations were expected and self-generated. Subjects performed a voluntary rise to toes task, whereby they simply stood up on their tiptoes while in either a posturally anxious or non-anxious condition. When they completed the task in the anxious conditions, a reduced magnitude of postural adjustment was observed and it took a longer time to complete the task, suggesting that subjects were more conservative and timid when they completed the task in conditions of postural threat. Pijpers and colleagues (2005) investigated motor adaptations in response to anxiety about falling that occurred in the multi-faceted, complex task of rock climbing. Though this study was not framed within the postural threat paradigm, the results are pertinent and applicable to the effect of anxiety on posture and body movement. In this study, subjects traversed across two identical rock faces: one close to the ground and one 5 meters above the ground. They reported that when subjects traversed in the elevated condition, climbing time and total number of explorative movements increased. In addition, subjects held onto the holds longer and performed slower movements. As a result, this study demonstrated that subjects continued to exemplify conservative and protective movements when completing a complex postural task in an anxious condition.

Investigation regarding the impact of anxiety about falling on postural control has not been limited to the healthy populations. Indeed, fear about falling is prevalent in pathological populations, and in particular, those with motor pathologies such as Parkinson's disease. For instance, in a slightly modified version of the postural threat paradigm, individuals with Parkinson's disease were asked to reach for a glass of water while standing either at the edge of a 0.6m high platform that either had an additional platform in front of the subject (non threatening) or no platform (threatening). In the threatening context when there was no platform in front of the PD patients, hand acceleration occurred for a longer time and their anterior COM velocity peaked at a later time (Doan et al., 2010). Other work in patients with Parkinson's disease patients revealed that symptoms of the disease, namely difficulty in gait initiation and maintain steady state gait, were exacerbated when they walked on an elevated walkway that induced a threat to posture (Kurek, 2005).

The general finding to emerge from this line of inquiry is that motor adaptations induce a conservative and protective movement strategy that can help reduce the risk of falls. In line with the common inverted U performance curve, it is possible that motor adaptations performed excessively or inappropriately with respect to the demands of the task and the environment may reduce the efficacy of this strategy. For instance, Delbaere and colleagues (2009) found that the reductions in walking speed observed in an elderly group that was afraid about falling was disproportionately large, suggesting that concern about falling elicited greater and possibly posturally detrimental gait adjustments.

2.2.3. Age dependent anxious motor adaptations. Findings resulting from the postural threat paradigm exploring how anxiety regarding impending fall episodes influence postural control have also provided unique insight into the realities associated with aging. In previous experiments in our laboratory that investigated whether age influences anxiety mediated changes to postural control, older adults were subjected to the postural threat paradigm and their motor adaptations during steady stance were compared to their younger cohorts. Interestingly, older adults showed the same pervasive effect of anxiety as younger adults (Brown, Polych, et al., 2006), suggesting that in this task, elderly subjects were able to adapt to the demands of the postural threat. However, older adults tended to adopt a more conservative strategy than younger adults during more demanding tasks within a posturally threatening environment. For instance, older adults who walked on a raised walkway demonstrated a more significant reduction in gait velocity and stride length than younger adults (Brown, et al., 2002). This preference towards a conservative strategy also carried into a task of obstacle negotiation. When older adults were asked to step over an obstacle while walking on an elevated walkway, they took longer to step over the object than when the platform was not elevated (McKenzie & Brown, 2004).

2.2.4 Attention and postural control. Postural control demands attention. Early evidence for the role of attention in postural control was provided by Lajoie and colleagues (1993) who asked subjects to sit, walk, stand on a firm surface, or to stand on an unstable surface while responding to a randomly timed auditory signal. It was observed that response times were longer in standing and walking conditions than when sitting in the chair. The authors concluded that the maintenance of posture was degraded when attentional resources were shared or allocated to the response task, and as such, confirmed that attention is a necessary component for postural control.

I have adopted the definition of attention in postural control as an allocation of cortical resources to the interpretation of sensory information and the development of subsequent motor commands in response to incoming sensory information (Lajoie, et al., 1993; Shumway-Cook & Woollacott, 2000). The allocation of attention to postural control often happens automatically and without explicit conscious direction or focus, although conscious focus does influence how attentional resources are allocated (Shallice, 1988; Siu & Woollacott, 2007). As such, research regarding attention during postural control is more concerned with the dynamics of implicit attentional allocation rather than the effects of explicit conscious focus to the task at hand. To explore interaction between attention and postural control, many more studies have investigated the effect of doing a secondary task, such as reciting numbers backwards or completing math exercises concurrently with postural control (Andersson, Yardley, & Luxon, 1998; Huxhold, et al., 2006; Olivier, Cuisinier, Vaugoyeau, Nougier, & Assaiante, 2007; Siu, Catena, Chou, van Donkelaar, & Woollacott, 2008), resulting in consistent findings that a secondary task reduces performance in a postural task.

Aging is known to affect attention (McDowd & Craik, 1988; Sparrow, Bradshaw, Lamoureux, & Tirosh, 2002). As such, the role of attention in regards to postural control has been extensively investigated in the aging population. For instance, older adults who experienced a destabilizing postural perturbation whilst counting backwards took longer to recover and were more likely to take a step in order to recover their balance than younger adults (Brown, Shumway-Cook, & Woollacott, 1999). Huxhold and colleagues (2006) reported that older adults demonstrated reduced balance performance whilst standing and concurrently completing a demanding secondary task, but did not show balance performance decrements when completing a simple task. In comparison, the younger adults demonstrated no deficits in balance performance in either the simple or difficult task. The authors interpreted these results to indicate that the demands for attention in the elderly during postural control are greater than younger individuals.

One possible reason for the decrease in attention to posture in the elderly is the finding that older adults are unable to flexibly allocate their attention to the posture task. Siu and colleagues (2007) demonstrated that healthy younger adults were able to prioritize postural control at the expense of the secondary task. In this study, subjects were asked to maintain their balance while also completing a task that required visual spatial memory under three different instruction sets: (1) give priority to posture, (2) give priority to the visual task, or (3) give attention to both tasks equally. In this case, when instructed to give priority to posture, the indicators of successful posture increased. When a similar task was repeated with elderly subjects (Siu, Chou, Mayr, Donkelaar, & Woollacott, 2008), they demonstrated an impaired ability to flexibly allocate their attention.

Along the same line of inquiry, Gage and colleagues (2003) further characterized the effect of anxiety about posture on attentional resources. In this study, older and younger adults responded to an auditory cue while walking on either a posturally non-threatening that was at floor level or a posturally threatening walkway that was raised off the ground. The authors found that response times increased when subjects walked along the raised, anxiety inducing walkway and the authors concluded that that anxiety about posture resulted in an increased need for attention to walking. Given these findings, there is a possibility that the motor changes observed in older adults may partly be a result of reduced processing capacity due to the presence of anxiety.

2.3 Motor Learning

2.3.1. Fundamentals of motor learning. Improving balance requires learning motor skills that are pertinent to successful postural control. Magill (1998, p. 129) defines motor learning as "…a change in the capability of a person to perform a skill that must be inferred from a relatively permanent improvement in performance as a result of practice or experience." Accordingly, there are four distinguishing attributes of motor learning (which are further described below) that arise from this definition. First, learning is the process of acquiring the capability for producing skilled action. Second, learning occurs as a result of practice. Third, learning cannot be directly observed but must be inferred by changes in performance and behavior, and fourth, the observed changes in performance, that is learning, is relatively permanent (Schmidt & Lee, 2005, p. 302).

Motor learning is a process that occurs as a result of a set of events or occurrences that happen to bring about change. These events are precipitated by repeated practice or experience in producing the skill, but are not always readily observable. Such events may include storing the motor pattern in memory or developing coordinated motor patterns in general response to a specific type of action. In postural control, the effect of a toddler who repeatedly practices standing is that he is eventually able to stand unassisted. The processes involved that are assumed to have occurred include development of appropriate muscle tone, interpretation of pertinent sensory information, and directing motor commands to the correct muscles, among others.

Direct observation of motor learning is not currently possible. For instance, much of the process of motor learning takes place in the motor cortex and cerebellum, and imaging of these changes during the process of learning is difficult at best. Although cortex and cerebellum changes as a result of learning have been observed through imaging (Desmond & Fiez, 1998; Ungerleider, 1995; Ungerleider, Doyon, & Karni, 2002), and damage to such structures impairs motor learning (Molinari et al., 1997), it is still impossible to accurately define the specifics of motor learning with today's technology (Magill, 1998). As such, learning is assumed to have taken place when performance indicators for the pertinent skill have improved. For instance, a five year old has learned how to ride a bike once she is able to ride unassisted without falling. In this case, it is inferred that the child has learned how to ride a bike because she has demonstrated the capability of doing so.

Motor learning results in relatively permanent changes in behavior. Once learned, a healthy subject does not easily lose the ability to ride a bicycle, nor is the ability to stand or walk quickly forgotten. Accordingly, when motor learning is purported to have occurred, evidence of relatively permanent changes in behavior is provided by means of a retention test some time after practice. Furthermore, Magill (1998, p. 129) suggests that in addition to the relatively permanent changes observed in motor performance, acquisition of the skill should produce generalized learning such that the learned skill is adaptable to other environments or modified tasks. To this end, the ability to generalize the learned task is often retested in either a new environmental context or in a slightly modified task, termed a Transfer test.

Repeated practice and experience is essential to motor learning and results in the progression of distinct stages of skill acquisition. The Fitts and Posner Three-Stage Model, as described by Magill (1998) forwards three distinct stages of skill acquisition. The first, or cognitive stage, involves conscious awareness and direction of motor patterns. This stage is often accompanied by narrative instruction from a skilled individual. In the cognitive stage, a learner generally makes numerous large errors as he attempts to understand and accomplish the specifics of the task. As an individual continues to practice the skill, he moves into the second, or associative stage. In this stage, a learner makes fewer errors since he has acquired the basic fundamentals of the skill. Environmental cues and movement patterns become associated such that reduced cognitive resources are needed to perform the task. The third, or autonomous stage, is characterized by internalization or habituation of the skill. Performance of the skill is automatic, and is performed consistently and with little error.

Wolpert & Flanagan (2010) suggest that the process of motor learning follows a stepwise progression that includes allocating appropriate sensory resources, learning the key features of the task, developing predictive and reactive control mechanisms, and developing higher level skills including anticipation and strategy. In the first phase of learning a new skill, subjects learn to attend to sensory resources such that they are informative to the task at hand. For example, a child who is learning to control his posture will learn to direct his attention on his somatosensory system to determine his body position with respect to the support surface. In the elderly subject with diabetic neuropathy, it may mean refocusing sensory attention on more useful sensory input, such as the visual or vestibular system (Horak, et al., 2002). In the second phase, subjects direct their attention on the key features of the task. A child would learn quickly that one of the key demands of postural control is to maintain adequate muscle tone in an effort to oppose gravity. The third phase of motor learning involves developing predictive and reactive control mechanisms to respond to the features of the task. In postural control, this includes appropriate motor responses to spontaneous sway to keep the COM within the BOS. The fourth phase involves developing higher-level skills, including anticipation and strategy. In postural control, these would be central set directed motor adaptations, such as leaning away from the edge of a cliff or an instinctive stiffening of the body in anticipation of a postural disturbance.

2.3.2 Attention and motor learning. Investigation about the motor acquisition process has resulted in the finding that learning a new motor skill requires attention. Along this line of research, Posner and Keele (1973, p. 813) remarked that initial skill acquisition required a conscious focus of attention which gradually diminished as the task became more automated. In an effort to confirm this speculation, Wrisberg and Shea (1978) asked subjects to learn a motor task (primary) or complete reaction probe task (secondary) either separately or concurrently. As subjects practiced the tasks over four days, reaction time for the secondary task decreased for the group who completed the tasks concurrently but did not change for the group that completed the secondary task independently. These findings imply that learning the motor task required attentional resources and as subjects became more proficient, that is, learning decreased, attentional resources were freed up for allocation to the secondary task.

In another study on the effect of attention on motor learning, Passingham and colleagues (1996) asked subjects to perform a motor task in which they learned to move their fingers in a certain sequential order. Subjects who learned the task while concurrently completing a verbal verb generation task were slower and made more errors than when the task was completed independently. These findings imply that allocation of attention is necessary for effective motor learning. As a follow up to these findings, Jueptner and colleagues (1997) had subjects learn or perform the same motor tasks as above while cortical activity was recorded using positron emission technology. Novel learning of the motor task resulted in cortical activity that was located in the dorsal prefrontal cortex and the right anterior cingulated cortex. Interestingly, these were the same areas of the brain that were activated in subjects who had previously learned the sequence but who performed the task while explicitly and consciously paying attention to their actions. This observation that new motor learning and the conscious allocation of attention activated similar cortical space implies that motor learning and attention are coupled and thereby may be dependent on one another. Further studies that investigate the behavioral effect of attention allocation on motor learning confirm these findings. For instance, learning was impaired when subjects completed a spatial finger mapping motor task while also attending to an auditory signal (Galea, Sami, Albert, & Miall, 2010), and in another study, motor learning was impaired when subject's attention was divided between a reaching task and responding to an auditory signal (Taylor & Thoroughman, 2007).

2.3.3. Postural motor learning and aging. Normal aging often results in degeneration of the sensory and motor systems, such as reduced visual acuity and muscle capacity, resulting in altered sensory input and motor execution. Balance training encourages practice in interpreting these altered sensory inputs and developing predictive and reactive control mechanisms that can be used to anticipate and react effectively to the demands of the environment. The goals of balance training are to improve confidence, mobility and function by providing comprehensive training that includes basic fitness and exercise components as well as specific anti-fall related exercises (Skelton & Dinan, 1999; Steadman, et al., 2003) that serve to counteract deficits that occur as a result of aging.

An assumption of balance training is the assumption that older adults possess the ability to acquire beneficial motor skills which can then be applied in their normal environments. Van Ooteghem and colleagues (2009) demonstrated that older adults are capable of learning optimal motor skills related to posture. In this study, older adults were exposed to multiple learning trials of pseudorandom translating postural oscillations. On both training day and when retested the next day, the progression of the variability in the angle of the subject's trunk was similar in both groups suggesting that both younger and older adults preserve the ability to maintain and improve trunk control. These results provide evidence that older adults are able to learn and retain adaptive postural control in response to continuous perturbations.

Further research suggests that motor learning during postural tasks is accomplished through learning a general postural strategy as opposed to learning specifics of the postural task. For instance, Van Ooteghem and colleagues (2008), using the same perturbation sequence as above, reported that subjects learned to minimize COM movement equivocally in both the random and the repeated segments. The authors suggested that the subjects did not learn the specific sequence of the repeated oscillations and that instead, they had learned a general strategy for maintaining postural control during the perturbations and subsequently refined those strategies during each learning trial. This implication is further supported in a study of younger adults who learned to walk on a treadmill while discordant visual stimuli were presented. The authors observed that training on the discordant treadmill resulted in rapid adaptation during a subsequent similar walking challenge, whereas those who did not train previously did not adapt as quickly (Batson et al., 2011). These findings are important when developing balance training programs for the elderly because it implies that general balance skills that are learned as part of a training program may be useful in the real-world.

2.3.4. Anxious interference in motor learning. One of the possible confounds in providing balance training for the elderly is that often these individuals have developed a fear of falling, resulting in anxiety about falling. Given the observation that anxiety negatively affects motor performance, a logical extension would be to infer that anxiety might affect motor learning as well. Schwenkmezger and Steffgen (1989, p. 79) suggested that motor behavior encompassed both motor learning and motor performance by indicating that " [motor behavior] comprises learning factors and performance-related processes that go along with the execution of a movement." The authors further postulated that anxiety altered the psychological and physical aspects of movement, and as such, the possibility remains that optimal motor behavior may be compromised. By extension, motor learning of optimal motor behavior could also be compromised.

Direct observation about the effect of anxiety on motor learning comes from Calvo and Ramos (1989) who observed smaller motor performance improvements compared with controls when anxious subjects learned a motor task in a dual-task scenario. This particular task required moving and rotating puzzle pieces (motor task) while responding to a randomly presented auditory cue (cognitive task). The authors suggested that the presence of anxiety reduced the availability of cognitive resources, making learning less efficient. As a result of their continuing observations that anxiety interfered with motor performance and learning, Calvo and Eysenck developed the Processing Efficiency Theory (1992) that postulated that decrements in motor performance were a consequence of inefficient processing of sensory feedback caused by anxiety. This initial theory was refined in 2007 as the Attentional Control Theory (ACT) (Eysenck, et al., 2007). The ACT postulates that anxiety alters the focus of attention away from the task at hand and towards the anxious stimuli, thereby impairing the performance or learning process unless compensatory measures are employed (Oudejans & Pijpers, 2009; Wilson, 2008).

Oudejans and Pijpers (2009) investigated whether compensatory behaviors could negate the effects of anxiety on a motor task. In one of their reported protocols, subjects practiced throwing darts at a target while holding onto rock climbing holds at either ground level or 2 meters above the ground. The authors hypothesized that practice of the task in an anxious environment would result in learning motor compensation strategies that could be useful in later anxious conditions. Indeed, the authors observed that subjects who practiced in the non-anxious condition showed a reduction in performance when throwing in the anxious condition compared to their performance earlier performance. However, those who trained in the anxious condition performed as well as their counterparts in the both non-anxious and anxious conditions, concluding that in this case, practice in an anxious condition negated the acute effects of anxiety on motor performance. The authors speculated that this performance outcome was achieved by the introduction of self-regulatory processes that directed motor and psychological adaptations that were beneficial in the anxious conditions.

2.4 Summary and Rationale of the Study

Falls among the elderly result in significant consequences and affect the faller, their caregivers and the health care systems. The psychological results of falling episodes are long lasting and debilitating, and can result in a higher fall risk, thus perpetuating a negative spiral of increasing health care costs, poor quality of life, and death. Fall prevention training, including balance training among the elderly has been shown to reduce the incidences of falls and can result in a significant benefit to the individual, their caregivers, the health care systems, and the economy.

Although balance training has been shown to be effective in reducing fall risk, to the best of my knowledge, the influence of psychological factors, such as postural anxiety on motor learning has received little or no consideration. From the documented evidence that anxiety has been shown to influence both the acquisition and execution of motor tasks, it is possible that anxiety may compromise the efficacy of fall prevention training protocols. Aligned with this possibility, the purpose of my thesis was to investigate the influence of postural anxiety on the acquisition, retention, and transfer of motor skills relevant to fall prevention.

Chapter 3: Methods

3.1 Subjects

Twenty younger adults (22.0 ± 2.7yrs; 13 females) participated in a postural motor learning task. Subjects were free, by self report, of neural pathologies or physical disorders that might interfere with their ability to learn or respond to the challenges. All subjects gave full and informed consent prior to participation in the study. The protocols of this study were approved by the Human Subjects Ethics committee at the University of Lethbridge in Lethbridge, Canada.

3.2 Procedure

3.2.1 Protocol. The protocol of this study followed a traditional motor learning paradigm comprised of Acquisition (Aq; Day 1), Retention (R) and Transfer (T; Day 2) phases (Schmidt & Lee, 2005). Participants were randomly divided into two testing groups that differed by training environment. The environmental intervention was designed to induce a fear or anxiety about posture and the training conditions were distinguished as posturally Non-Anxious (NA) or Anxious (A). The NA group completed all training while standing directly on a moving platform and the A group trained while standing with each foot on a separate wooden pedestal that was placed on top of the moving platform. The wooden pedestals were 13.5cm x 41cm x 9cm high and placed next to each other with an approximate two centimetre space between them. In this way, subjects were positioned nine centimetres higher in the A condition and a step or slip in any direction would have resulted in an inconvenient step off the pedestals in order to regain balance (Fig. 3.1).

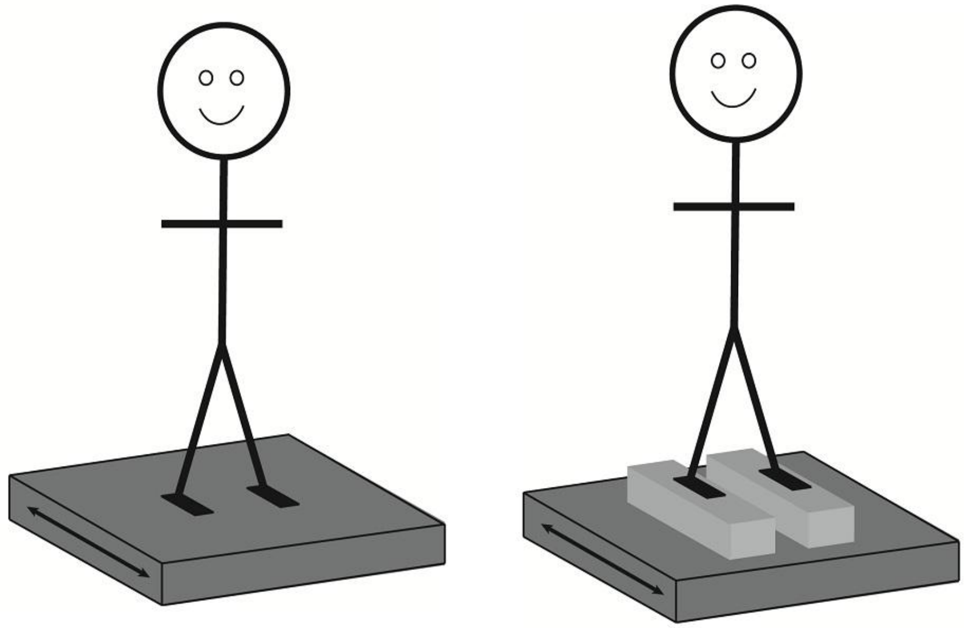

Figure 3.1 Subjects stood on a platform that oscillated in the fore-aft direction. I created an anxious environment by increasing the perceived risk of falling by requiring subjects to stand on two wooden blocks during the balance challenge.

The ability for this protocol to induce anxiety was investigated prior to the current study using a separate group of participants from whom we recorded measures of physiological arousal and assessed anxiety levels using verbal questionnaires (See Appendix A).

Day 1: Acquisition. Prior to training, baseline physiological arousal was measured for each participant. Measurements were acquired while subjects were sitting and relaxed for 45 seconds. Subjects then stood for 45 second trials on either the platform or the pedestal, depending on their training condition. Subjects crossed their arms across their chest and looked at a point on the wall in front of them approximately 3 meters away. They were instructed to maintain their balance as best as they could while keeping their feet fixed and refraining from taking a stabilizing step if at all possible.

Subjects then completed 36 trials in which balance was challenged by continuous Anterior-Posterior (A-P) platform translations of varying magnitudes and accelerations. The 36 test trials were presented as six blocks of six trials with approximately one minute between each trial. This between trial interval allowed the data collection computers to be readied between trials. Subjects sat down and rested for at least three minutes between each block.

Day 2: Retention and Transfer. Participants returned the next day for three consecutive Retention trials and three consecutive Transfer trials. Subjects performed Retention trials in the same NA or A condition as they had trained in the day prior, while Transfer tests were completed in the alternate condition to assess the generalizability of motor learning between A and NA environments. After a sitting baseline trial that was the same as in Day 1, the first testing condition, which was either the Retention or Transfer test, was counterbalanced between subjects. Trial structure and testing protocols were the same as Day 1. In accordance with this protocol, all subjects completed R and T tests in which motor performance was re-assessed in both similar and dissimilar training environments, and the testing protocol can be seen in Figure 3.2.

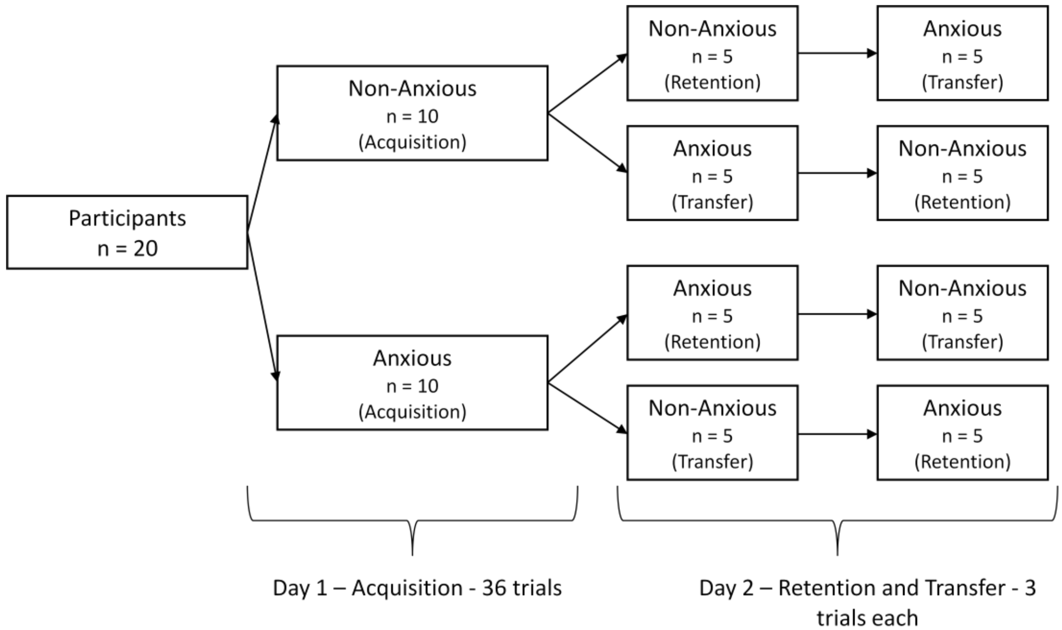

Figure 3.2. Experimental design of my study, including participants, group assignments, and testing conditions.

3.2.2 Postural Translations. The perturbation in this study was designed in accordance with Van Ooteghem and colleagues' (2008) study on motor learning during a postural task. Accordingly, subjects stood on a platform that translated in continuous, seemingly random sinusoidal oscillations for 45 seconds for each trial. The amplitudes of the first and last 15s of each trial were random while the amplitudes of the translations during the middle 15s were identical between each trial (Fig. 3.3). This between trial repetition allowed for consistent analysis of the motor response from identical motor stimuli. Participants were not informed and did not indicate any awareness of this between trial repetition. The frequency of the oscillations remained constant throughout testing at 0.5Hz but the random amplitude of each oscillation varied between the equipment limited maximal displacement of ± 6.35cm (*SmartEquitest System Operator's Manual*, 2001) resulting in variable translation velocity. Given the fixed frequency and maximum, equipment limited possible amplitudes of the translation sequence, the maximum possible translation velocity was .099m/s. The maximum translation velocity used in my study were slower than the 0.5Hz, ±15cm (maximum calculated velocity of 0.236m/s) translations used by Van Ooteghem and colleagues (2008) and slower than those used by Ko and colleagues (2003) who used 0.73Hz, ±11.5cm translations, yielding a maximum velocity of 0.264m/s. They were in line with those used by Buchanan and colleagues (1999) in their 0.5Hz condition using a ± 6.0cm, yielding a maximum velocity of 0.094m/s

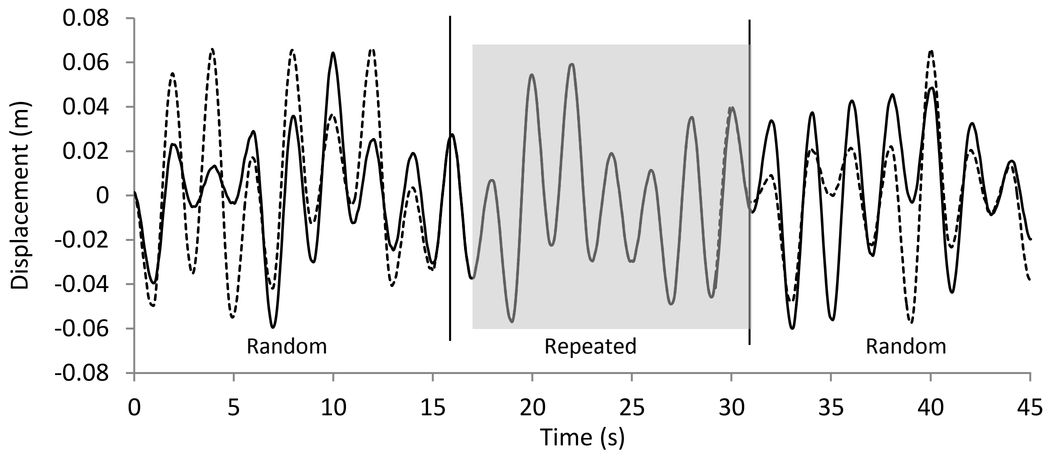

Figure 3.3. : Displacement profiles of the sinusoidal translations of two example trials (solid & dashed). The amplitudes of the middle 15s segment are identical for each trial, while the amplitudes of the first and last segments are random. Frequency is fixed at 0.5Hz. The greyed box represents the segment analyzed, which started after the first half cycle of the repeated segment in order to avoid contamination from the preceding random segment.

3.2.3 Equipment. The continuous, sinusoidal translating postural oscillations of the platform were produced by custom programming of a SMART Equitest CRS Neurocom®. Only the surface translation capabilities of the system were utilized and the system was modified by removal of the visual surround to ensure subjects could not respond to the disturbances with a grasp response. Forces associated with body movement were captured using the dual AMTI® force plates embedded in the surface of the SMART Equitest CRS, recorded at the equipment defined sampling frequency of 100Hz (*SmartEquitest System Operator's Manual*, 2001).

Postural responses to the oscillations were quantified using a six camera motion capture system (Peak/Vicon®) that tracked passive reflective markers located at key body landmarks and recorded at the native camera sampling frequency 120Hz. An eight segment digital representation of the body was constructed using 11 markers affixed bilaterally to the fifth metatarsal, lateral maleolus, lateral femoral condyle, greater trochanter, and acromion process, as well as a single marker affixed to the center of the forehead. This marker configuration provided representations of the movement of both feet, both legs, and both thighs, the head-arms-trunk segment, and head (Winter, 2009). A single marker was also affixed to the translating platform in order to record the actual postural translation sequence.

Anxiety during this protocol was inferred by physiological arousal and was measured by galvanic skin conductance (GSC) with a UFI Model 2701 Bioderm® Skin Conductance Meter sampled at a common multiple of the force plate and camera sampling frequencies: 600Hz. Subjects wore Ag-AgCl sensors on the palm surface of the second and third fingers of their right hand to capture physiological arousal.

All data were saved and stored offline for further analysis. Reduction of offline data was accomplished in Matlab® (Version 7.8, The Mathworks Inc., Natick, MA, 2000) using algorithms that I wrote explicitly for this study. Reduced measures were then transferred to and organized in Microsoft Excel (2007). Statistical analysis was performed using SPSS (Version 17).

3.2.4 Outcome Measures.

Galvanic Skin Conductance. Anxiety was inferred by tonic physiological arousal measured by Galvanic Skin Conductance (GSC). Because of the wide inter-subject variability normally observed in the GSC signal, between-subject normalization of the GSC data was performed by subtracting the average of the individual's baseline trial from all other trials that day and then dividing by the maximum observed value of the day (Lykken & Venables, 1971). I was interested in the effect that the height and constraints of the pedestals had on anxiety as inferred by measuring physiological arousal. The GSC response is primarily determined by psychological state, such as feelings of anxiety and fear, and is also elicited in response to muscle movement and startle responses (Sibley, Mochizuki, Esposito, Camilleri, & McIlroy, 2008), which are respectively referred to as the tonic and the phasic responses (Sibley, Mochizuki, Frank, & McIlroy, 2010). As such, it was necessary to exclude the phasic GSC response that resulted from both the startle response as a result of the start of the trial and the muscle activation necessary to respond to the perturbations. To determine the latency of the phasic muscle response, I referred to Sibley and colleagues (2008) who observed that the phasic GSC response onset began at 1890 ± 329ms, which is indicative of reflex latency and thus systematic between participants of similar age. Accordingly, I applied this knowledge to exclude the phasic effects of the task and included a possible margin of error by using the GSC recorded from only the first 500ms of each trial. In this way, my assumption is that I ascertained the GSC that was induced by the anxious environment rather than the physiological response resulting from the muscle contractions and startle responses.

Postural Patterns. I used a postural translation of varying amplitude and constant frequency of 0.5Hz. In line with Van Ooteghem (2008; 2009) and colleagues, this frequency represents a transitional border between characteristic postural control patterns, and therefore provides an opportunity to investigate preferences and proficiency of the “rigid mode” and “ankle mode” movement patterns. In this study on postural motor learning the authors observed that over the course of Acquisition, COM amplitude decreased and phase alignment between the translation sequence and the COM increased. Furthermore, a strong hip-platform correlation emerged later in training, suggesting that participants introduced an additional degree of freedom in order to efficiently maintain their balance. They interpreted these findings to suggest that an observable shift between strategies that included adding multiple degrees of freedom at the ankle and then at the hip had occurred. Proficiency in the postural task was measured by the ability to counteract the effect of the translation sequence such that the effects of the movement were not transferred to superior landmarks, and in particular, the COM. In line with these findings, I expected postural anxiety to affect the ability to learn and refine this optimal movement pattern. To this end, my outcome measures, below, focused on the proficiency and improvement in the ankle and ankle-hip movement patterns. I examined how these movements were refined during Acquisition and the ability to Retain and Transfer the refined motor patterns the next day.

Kinematic Data Processing. The motor response to the translation sequence was quantified using time series analysis of the recorded kinematic data set. To compare similar motor responses across all subjects, I restricted analysis to the postural translations that were similar between trials and subjects. As such, I compared only the segment that was repeated between each trial. To minimize contamination from preceding segments, the first half-cycle during the repeated segment was discarded because of possible variation of motor responses from the random amplitude that had been generated in the previous cycle. As a result, postural data that were recorded between the start of the 17^{th} second and the end of the 30^{th} second were included for analysis (Fig. 3.3). Data analysis was restricted to the sagittal plane to quantify the response of the body to the anterior-posterior translations.

All data from kinematic markers including the single marker located on the translating platform were filtered with a zero phase 4^{th} order lowpass Butterworth filter with a cut-off frequency of 5Hz. The COM was derived using weighted average of each body segment according to standard anthropometric measures (Winter, 2009). The mean of each bilateral marker pair was calculated, resulting in a single time series for each landmark of interest including the toes, ankles, knees, hips, COM, shoulder, and head. Joint angles for the ankle, knee, and hip were calculated using the known positions of the averaged landmarks located at the vertex of the joints and the known positions of the involved segment endpoints.

Postural Performance Measures. Six measures were identified to determine the effects of the postural translation on the anterior-posterior motion of the body segments. (1) The Mean Absolute Amplitude (MAA) of landmarks, (2) the MAA of angular joint rotations, (3) the Instantaneous Coupling (IC) between the translation sequence and landmarks, (4) the IC between the angular displacements of joints-linkages, (5) the

Discrete estimate of Relative Phase (DRP) between the translation sequence and landmarks, and (6) the DRP between the angular displacements joint-linkages. These measures provided a means to examine of the effect of the postural translation on body sway with respect to the environment as well as a method to investigate the inter-joint coordination during the translation sequences.

(1) - MAA of landmarks (ankle, knee, hip, COM, shoulder, head). The MAA for each landmark was derived by locating the maximum and minimum anterior-posterior position of the landmark in each cycle of the postural translation. The minimum value was subtracted from the maximum, providing the total absolute displacement of the landmark in response to the each anterior or posterior excursion. The series of absolute displacements for each landmark within each trial was combined into a single aggregate mean for that trial (Fig. 3.4). In accordance with previous findings, lower mean amplitude represented reduced sway with respect to the environment and subsequently an increased dampening of the body segment (Buchanan & Horak, 1999).

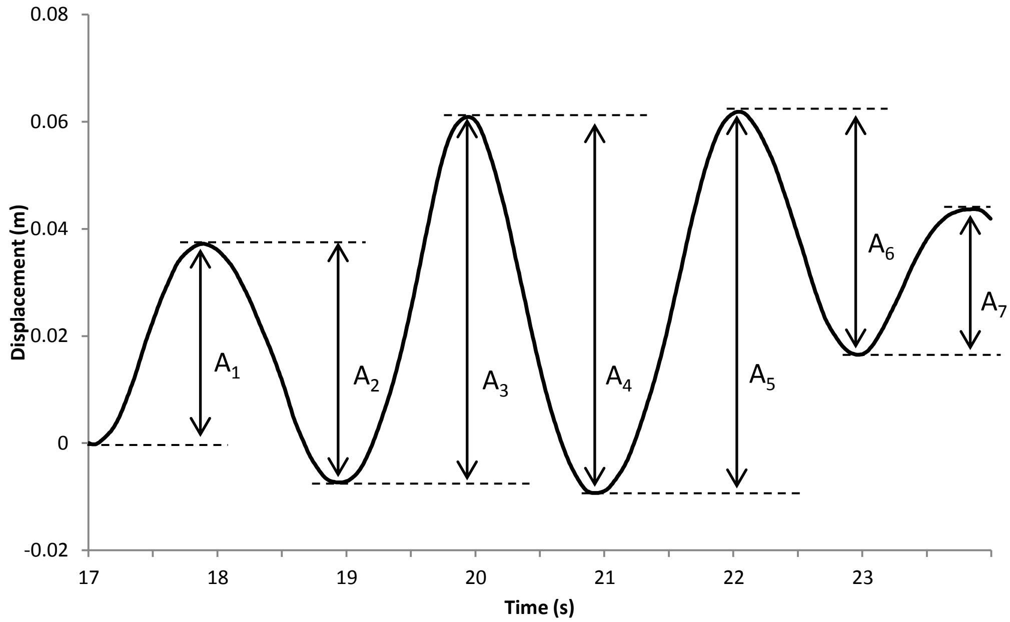

Figure 3.4 The MAA was calculated by averaging the absolute displacement between the local extrema (A_n) in each half cycle. Shown here is the COM trajectory and from a single subject over the first seven seconds of the analyzed segment (analysis started at the 17th second of each trial).

(2) - MAA of joints (ankle, knee, hip). In addition to the MAA of the landmarks, I also calculated the MAA of the angular displacement of the joints using the same method as outlined above. This measure provides inference of the active involvement of the joint in maintaining balance throughout the perturbation (Ko, et al., 2003). Lower amplitudes indicated increased rigidity and less active involvement of that joint.

(3) – IC of landmarks (ankle, knee, hip, COM, shoulder, head). Instantaneous Coupling of the motion of the body with respect to the postural translation was investigated. This was accomplished by calculating the zero time lag cross correlation coefficient between the platform motion and the motion at each landmark in the anterior-posterior direction as well as the angular displacement of the joints. The magnitude of the cross correlation coefficient indicates whether the motion of the two series is coupled or

independent of each other, providing a measure of the ability of the motor control system to counteract the platform movement (Ko, et al., 2001, 2003). A cross correlation coefficient close to zero indicates that the series move independently of each other while scores close to positive one indicate that the motions are completely synchronized. Correlations that approach negative one indicate that the movements are synchronous but out of phase, that is, the series move exactly opposite of each other. Synchronized movements suggest that the translation pattern was not effectively counteracted by the efforts of the postural control system, resulting in transfer of the platform movement into superior body segments.

(4) – IC of joint-linkages (ankle-knee, ankle-hip, knee-hip). The IC of the joint-linkages was also investigated by calculating the cross-correlation coefficient of angular displacements of two separate joints. A zero time lag cross correlation coefficient was calculated for Ankle-Knee, Ankle-Hip, and Knee-Hip joint linkages. This magnitude of the correlation coefficient indicated synchronization between the movement of joints, where a high correlation signified that the joints moved synchronously and a low coefficient demonstrated that the joints moved independently of each other. Correlation and synchronization between joints indicates a coordinated, energy efficient effort to counteract the effects of the translation sequence, and the magnitude of coupling between specific joint provides insight into whether subjects have adopted multi-joint movement patterns, such as an "ankle-hip" mode, or single joint movement patterns, such as the "ankle mode."

(5 & 6) – DRP of landmarks (ankle, knee, hip, COM, shoulder, head) and of joint-linkages (ankle-knee, ankle-hip, knee-hip). The DRP was used to investigate movement

relative phase between the motion of the platform and movement of the body at each landmark, as well as between joint-linkages. The DRP is the measure of relative timing between events in an oscillating target series in relation to a full cycle of an oscillating reference series. This measure provides valuable insight into coordination between two oscillating series. A positive value indicates that the oscillation of the reference series precedes the oscillation of the target series, and negative values indicate that the reference lags behind the target. This is the single common measure most frequently used in postural translation studies to describe landmark and joint coupling and coordination (Buchanan & Horak, 1999; Ko, et al., 2001). The DRP is commonly used to infer capability and improvements in predictive control during postural translations (Van Ooteghem, et al., 2008), suggesting that subjects have learned and refined a generalized motor pattern that can effectively anticipate and compensate for the random movements of the translation sequences. When measuring postural response to an oscillating translation sequence, a negative value suggests that the postural corrective action is active and in anticipation to the translation sequence, while a positive value suggests a passive and compensatory response.

The DRP is expressed as a fraction of the angular cycle of the reference series. To calculate this measure, I used a similar method to Dijkstra and colleagues (1994), which involved generating and combining four series of discrete relative phase values of the peaks and valleys for both the displacement and velocity trajectories. This provided a comprehensive comparison of timing between multiple discrete events of the reference and target series, as shown in Figure 3.5. In order to calculate the DRP, a peak-picking algorithm was used to identify peaks and valleys for both the displacement and velocity time series of the anterior-posterior motion of the platform and landmarks, as well as the angular motion of each joint. Velocity at each point in time was calculated by finding the difference between the displacement of the next and prior samples and dividing that value by the time difference of the respective samples. Previous studies have calculated the DRP in this manner using sampling frequencies as low as 50Hz (Dijkstra, et al., 1994). The sampling frequency of my kinematic data was 120Hz, resulting in increased temporal resolution and equally valid estimates of the DRP.

The procedure to calculate the DRP is as follows (Dijkstra, et al., 1994; Ko, et al., 2003). All trajectories were first smoothed using a normalized Gaussian filter with window size of 1s and a standard deviation of 0.18s. Peaks (and valleys) in the displacement trajectories of each trial were identified as the maximum (or minimum) value using the criteria that they must differ from the adjacent valleys (or peaks) by at least 20% of the range of the entire trial. In the velocity trajectories, the criteria was 50% of the range. Each peak or valley of the reference series was then used to find matching peaks or valleys in the target series of the same type that occurred within a ½ cycle of the occurrence in the reference. This value was then divided by the average cycle time of the reference series and multiplied by 2π, resulting in an angular measure of relative phase difference between the two series. All four time series of the relative phase values that were derived from the peaks and valleys of the displacement and velocities were then combined for an overall time series. The mean value of this series was calculated and values close to zero indicated that the phases were in sync, negative values indicated that the target series led the reference series while positive values indicated that the target series lagged behind the reference series. When calculating the DRP between the movement of the platform translation and joint motion, the movement of the platform was always the reference series. When calculating the DRP between motion of one joint with another joint, the distal joint was used as the reference series.

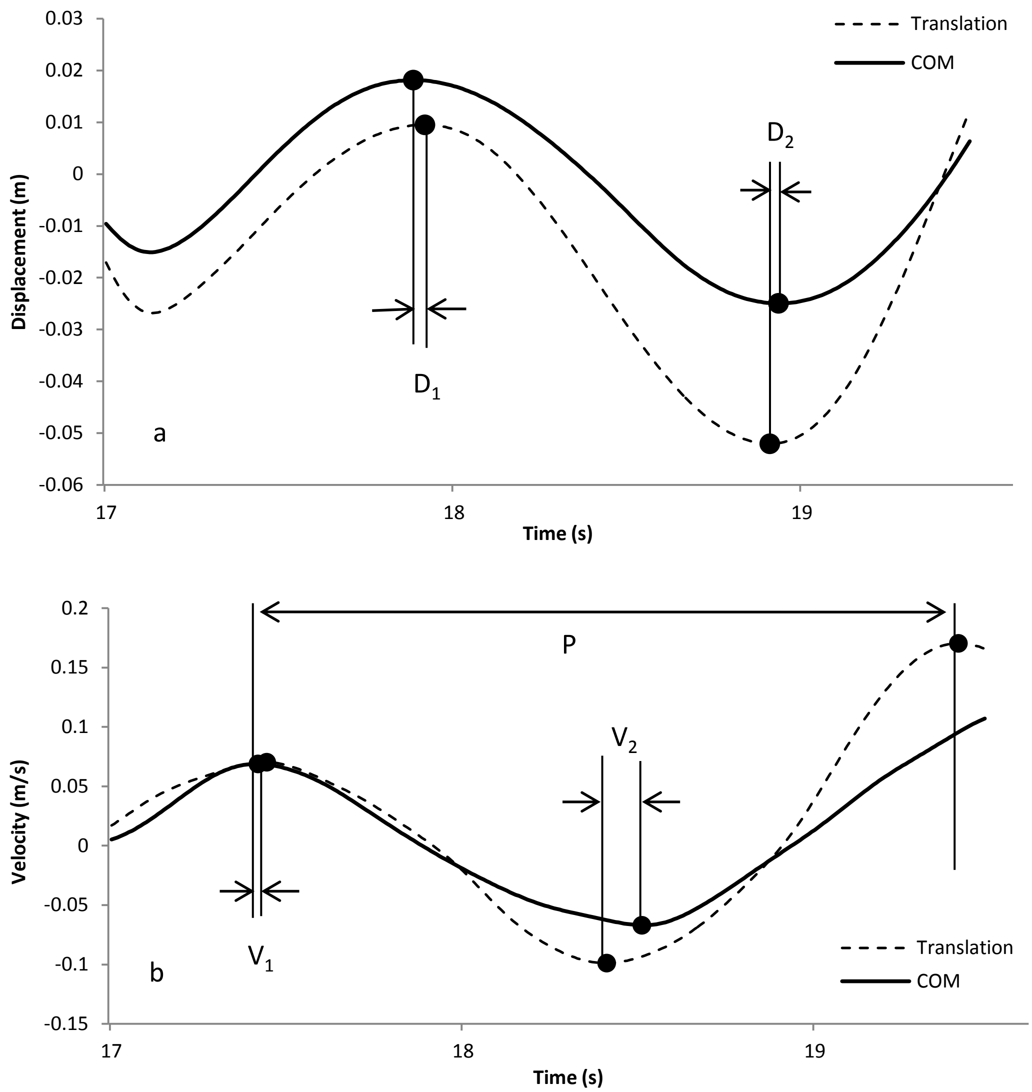

Figure 3.5 The DRP was calculated by finding the local extrema for the (a) displacement and (b) velocity trajectories of a reference (here, Translation) and target series (here, COM). The difference in time between the matched local extrema (D_n, V_n) represented the phase shift between the reference and target, and the ratio of the phase shift and average oscillation period of the reference (P, only on b here, but calculated separately for both displacements and velocities) was calculated. The ratio was then multiplied by 2π to provide an angular value of the discrete relative phase shift between the reference and target. All calculated relative phase shifts for both displacement and velocity were averaged to provide one aggregate measure of DRP. The first three seconds of the analyzed segment (analysis began at the 17^{th} second) are shown here from one representative subject.

3.2.5 Statistical Analysis. Prior to statistical analysis, data sets were scanned for missing values. Missing values were replaced with the mean of the trial prior and trial after, providing that there were less than two missing trials over all for the subject and that the trial did not fall on an endpoint of testing condition. There were no missing values in the GSC data set, and kinematic data were missing for seven trials. Four of these trials met the criteria for replacement. Data for the remaining three trials included three retention trials from one subject assigned to the NA group, and these data were excluded from analysis.

Phases. In order to answer my research question of whether anxiety about postural control interfered with motor learning, I performed separate analysis of the effect of anxiety on the Acquisition of refined movement patterns for postural stability and on the Retention and Transfer of these optimal patterns. Analysis of the Acquisition phase involved comparing motor performances throughout the 36 trials of Acquisition on Day 1. In accordance with studies on Transfer and Retention of learned skills, motor performance during Retention and Transfer trials were compared against the motor performances observed after training, that is, during the Trained phase. As such, motor performance during the last three trials of the Acquisition phase (Trained) was compared to the motor performance during the three Retention and three Transfer trials the next day.

Anxiety. Anxiety was inferred by the physiological response of the Galvanic Skin Conductance (GSC). GSC levels were compared between training groups on day one to determine the physiological effect of standing on the pedestal. I used was used a 36 x 2 (Trial x Group) Repeated Measures Analysis of Variance (RM-ANOVA) to determine whether there were differences in physiological arousal based on training condition during the Acquisition phase on Day 1. I used a 2 x 3 x 2 (Phase x Trial x Group) RM-ANOVA was ascertain differences in physiological arousal within each subject between the Retention and Transfer phases.

Motor Learning. Six measures, as described above, were used to assess postural performance during this motor learning task. These measures included the Mean Absolute Amplitude (MAA) of landmarks, the MAA of angular joint rotations, the Instantaneous Coupling (IC) between the translation sequence and landmarks, the IC between the angular displacements of joints-linkages, the Discrete estimate of Relative Phase (DRP) between the translation sequence and landmarks, and the DRP between the angular displacements joint-linkages.

Indicators of postural performance were analyzed using three-way RM-ANOVAs. To assess motor refinement during the Acquisition phase, I conducted six separate RM-ANOVAs on each of the dependent variables. Dependent variables pertinent to landmark outcomes (MAA landmarks; IC landmarks; DRP landmarks) were assessed using separate landmark x trial x group (6 x 36 x 2) RM-ANOVAs. Dependent variables pertinent to joint movement (MAA, joints) were assessed using a joint x trial x group (3 x 36 x 2) RM-ANOVA, and dependent variables pertinent to joint-linkages (IC, joint-linkages; DRP, joint-linkages) were assessed using joint-linkage x trial x group (3 x 36 x 2) RM-ANOVAs.

To assess motor refinement during motor learning, I conducted six separate RM-ANOVAs on each of my dependent variables, collapsed over trials within each phase

(Trained, Retention, and Transfer) of interest. Dependent variables pertinent to landmark outcomes (MAA, landmarks; IC, landmarks; DRP, landmarks) were assessed using separate landmark x phase x group (6 x 3 x 2) RM-ANOVAs. Dependent variables pertinent to joint movement (MAA, joints) were assessed using a joint x phase x group (3 x 3 x 2) RM-ANOVA, and dependent variables pertinent to joint-linkages (IC, joint-linkages; DRP, joint-linkages) were assessed using joint-linkage x phase x group (3 x 3 x 2) RM-ANOVAs.

Post hoc follow-up was completed using paired t-tests and one-way ANOVAs where appropriate and α was adjusted with Bonferroni correction for tests with multiple comparisons. Alpha (α) was set at 0.05.

Chapter 4: Results

No falls or missteps that required extensive balance recovery strategies occurred during the course of the study. Despite my directives to resist taking a step, almost all participants were startled by the first exposure to the translation sequence, resulting in a small, shuffle-like step to stabilize balance. These steps did not extend beyond the edge of the pedestal or platform and all subjects regained full control within the first five seconds of the trial. Because analysis of the trials did not start until the 17^{th} second, these trials were included in analysis.

4.1 Anxiety

Comparisons between physiological arousal revealed that GSC levels were higher when subjects stood on the pedestal in the A condition. Analysis of tonic GSC during Acquisition on day one revealed an effect for trial ($p < 0.001$) and a main effect for group ($p = 0.036$). Mean GSC was .487 (±.032) S for the NA group and .590 (±.032) S for the A group.

Analysis of Tonic GSC on day two between the Retention and Transfer phases revealed a Phase x Trial x Group interaction ($p = 0.016$), as demonstrated in Figure 4.1. Post-hoc follow up revealed that the NA group had higher GSC values in the first trial of the Transfer phase than in the first trial of the Retention phase. As per the protocol of the study, this indicates that subjects had higher GSC when those practiced in NA were tested in the A condition. Furthermore, the A group had higher GSC values in the first trial of the Retention phase than in the first trial of the Transfer phase. As per the protocol of this study, these findings occurred when those who practiced in the A group were tested in the A condition. These findings were maintained when collapsed over trial, as indicated by a Phase x Group interaction (p=0.035), and together, indicate that subjects had higher GSC when tested in the A condition.

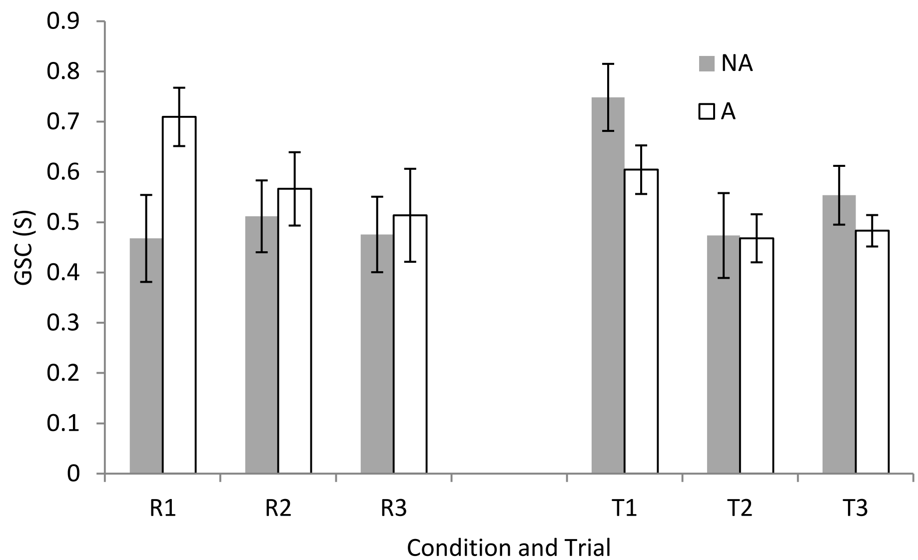

Figure 4.1: A phase x trial x group interaction (p=0.016) of the GSC Values of all 3 trials on Day Two for Retention (R) and Transfer (T) phases. In the NA group, GSC was higher when they performed the task in the first trial in the A environment (here, Transfer) than in the first trial of the NA environment (here, Retention). For the A group, GSC was higher when tested in the first trial of the A environment (here, Retention) than when they performed the task in the first trial in the NA environment (here, Transfer).

4.2 Postural Control

4.2.1. Acquisition. Table 4.1 provides a summary of main effects and interactions from analysis of landmarks, joints, and joint linkages.

	l	l x g	t	t x g	l x t	l x t x g	g
MAA Landmarks	***		*				
IC Landmarks	***	*			**		
DRP Landmarks	***		**	0.094	***		

	j	j x g	t	t x g	j x t	j x t x g	g
MAA Joints	***	0.053			***		
IC Joint-linkages	***		***		***		
DRP Joint-linkages	*			0.07	0.065		

Table 4.1: Summary table of main effects and interactions for measures in the Acquisition phase. Trends with p-values below 0.1 are included for informational purposes. l – landmarks, j – joint or joint-linkage, g – group, t – trial. *** - p<0.001, ** - p<0.01, * - p<0.05.

MAA of landmarks (ankle, knee, hip, COM, shoulder, head). Figure 4.2a represents the MAA for landmarks during the Acquisition phase. No interactions were observed. A main effect for landmark ($p < 0.001$) was observed, suggesting that regardless of group assignment, the amplitude of movement at each landmark was different. Post-hoc comparison revealed that the MAA at the ankle, knee, hip and COM decreased as the number of joints between the landmark and the platform increased, though the MAA of the shoulder and head did not differ from each other.

A main effect for trial ($p<0.039$) was observed, indicating that the amplitude of body movement changed with practice. Post hoc analysis using an adjusted alpha for multiple comparisons ($\alpha/35$) indicated that these trial effects were significant. The main finding from post-hoc analysis was that the mean amplitude decreased with practice. The largest improvements were observed in the first four trials.

I C of landmarks (ankle, knee, hip, COM, shoulder, head). A significant landmark x group interaction emerged ($p=0.015$), as represented in Figure 4.3b, suggesting that the magnitude of correlation between the movement of the platform and the landmarks was differed between group assignment. This interaction failed to maintain significance in post hoc analysis, though the magnitude of correlation of the head in the NA group tended to be lower than the A group ($p = 0.067$).

A significant landmark x trial interaction ($p<0.01$) indicated that, regardless of group, the magnitude of the correlations of each landmark differed over the course of Acquisition. Post hoc comparison between the IC at each landmark for each trial, using an adjusted alpha ($\alpha/5$), revealed that the IC at the knee was different from the IC at the COM for all but two trials in the first half of Acquisition and seven trials in the second half ($p<0.01$). For every trial, the IC at the ankle and knee differed from the IC at the hip, COM, shoulder, and head. Similarly, the IC at the hip and COM differed from the IC at the ankle, knee, shoulder, and head, and the IC at the shoulder and head differed from the IC at the ankle, knee, hip, and COM ($p<0.01$).

DRP of landmarks (ankle, knee, hip, COM, shoulder, head). Figure 4.3c represents the DRP of each group for landmarks during the Acquisition phase. A landmark x trial effect ($p <0.001$) revealed that regardless of group, differences in relative phase between the platform and each landmark changed over the course of Acquisition, as represented in Figure 4.2c. Post hoc analysis using an adjusted alpha ($\alpha/5$) revealed that for every trial, the discrete relative phase between the ankle and the knee, hip and COM, and shoulder and head were similar ($p>0.01$). Additionally, relative phase between the knee and the COM was similar in all but six trials (five in the first half and one in the second half), and between the knee and the hip was similar in twelve trials (eight in the first half and four in the second half). All other comparisons resulted in significant differences between the landmarks for each trial ($p < 0.01$). It is worth to note that a slight trend towards a trial x group interaction ($p=0.094$) emerged in this analysis.

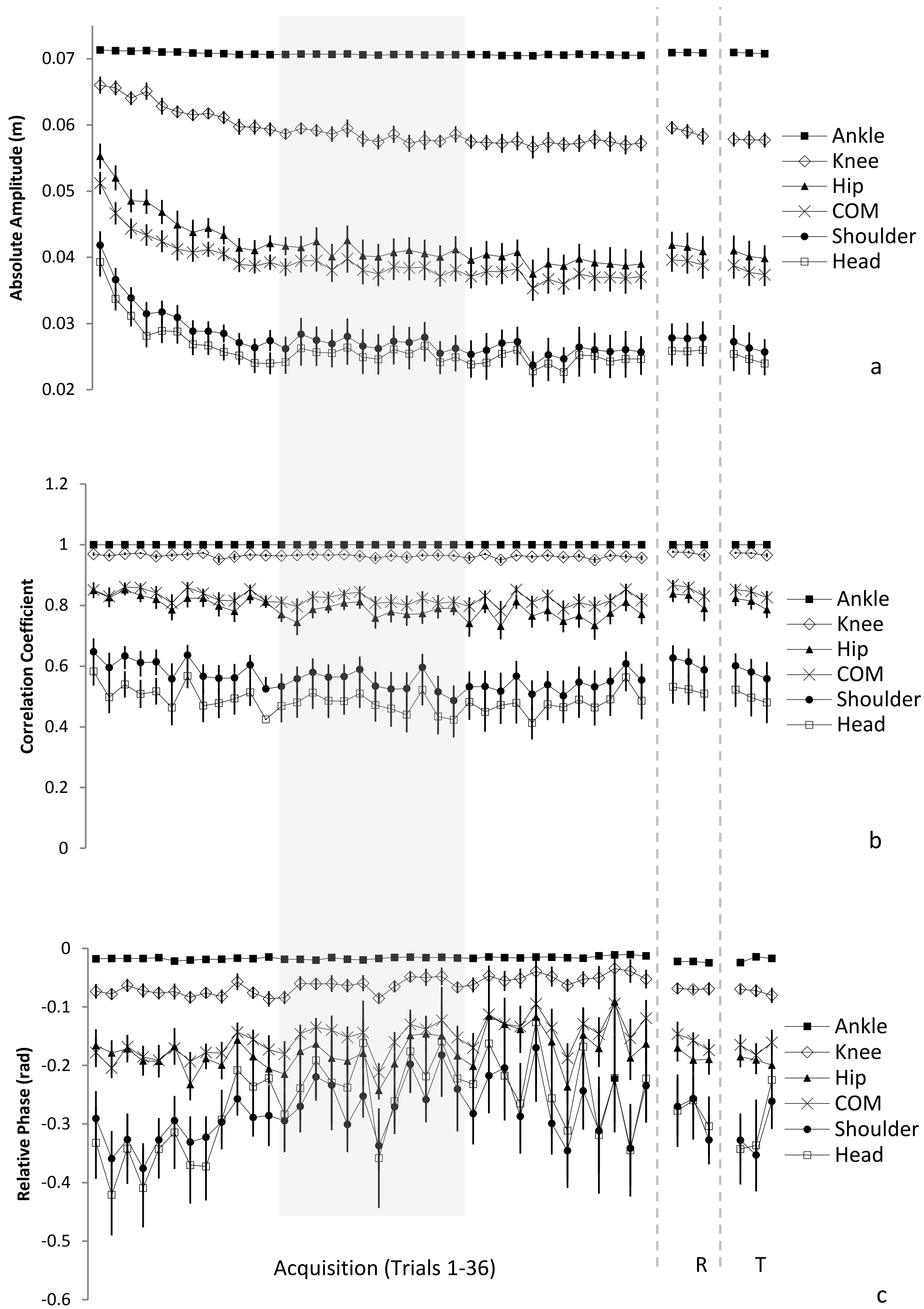

Figure 4.3: Measures of postural control at each landmark for each trial during Acquisition, Retention (R) and Transfer (T) phases. Data are collapsed over group. (a) represents the MAA of each landmark, (b) shows IC between each landmark and the platform translation, while (c) demonstrates the DRP between the platform translation and each landmark.

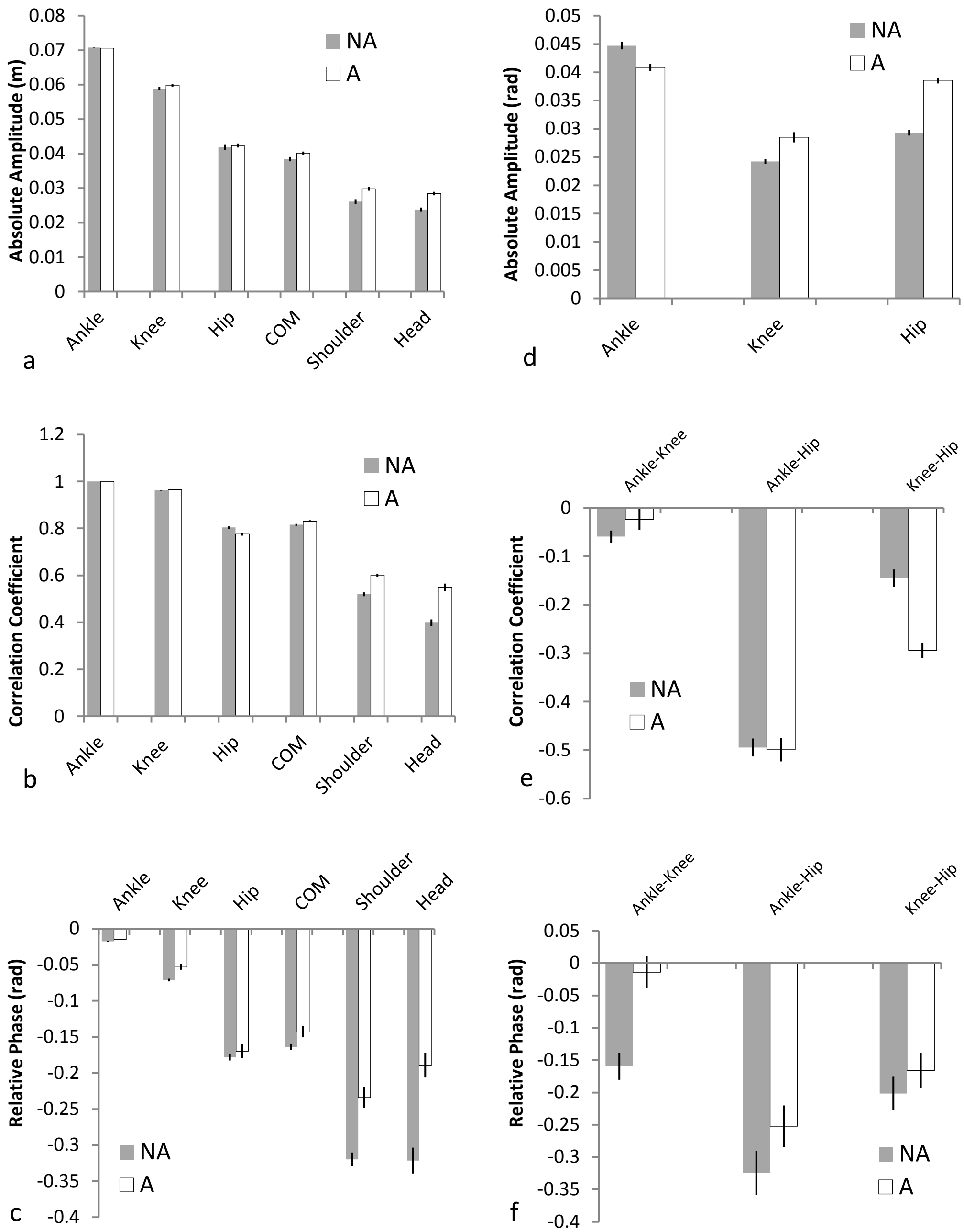

Figure 4.2: Measures of postural performance during Acquisition for each landmark, joint, and joint linkage, collapsed over trial. (a) MAA of landmarks (b) IC of landmarks (c) DRP of landmarks (d) MAA of joints (e) IC of joint-linkages (f) DRP of joint-linkages

MAA of joints (ankle, knee, hip). There was a trend towards a joint x group interaction (p=0.053), observable in Figure 4.3d, suggesting that the relative contributions of each joint to postural control differed between training condition. However, post hoc analysis failed to distinguish any differences in joint MAA between groups. No other group effects or interaction emerged.

A joint x trial interaction ($p<0.001$) indicated that regardless of group, the differences between the amplitudes of angular displacement at each joint changed over the course of Acquisition (Figure 4.4a). Post hoc analysis using an adjusted alpha ($\alpha/2$) revealed that there were significant differences between the MAA of each joint on trial 12 and 13, as well as trials 16 through 36. Pairwise comparisons revealed that this difference was driven by a significant increase in the amplitude of the ankle in comparison to the other joints after trial 12 (Fig. 4.4a).

IC of joint-linkages (ankle-knee, ankle-hip, knee-hip). A joint x trial interaction ($p<0.001$) suggested that the magnitudes of correlations changed during Acquisition, and this change was independent of group assignment. Post-hoc comparisons of the differences between joint-linkages at each trial, using an adjusted alpha ($\alpha/2$), revealed significant differences between the linkages for trials 6, 7, 8, 10, and 12 through to 36. In particular, there was a larger negative correlation for the ankle-hip linkage than for the ankle-knee linkage around trial 7. In addition, the magnitude of the correlation of knee-hip linkage became stronger in a negative direction at trial 12 (Figure 4.4b) compared to the other two joint-linkages, and this difference persisted for the remainder of the trials. All other main effects or interactions did not differ.

DRP, joint-linkages (ankle-knee, ankle-hip, knee-hip). A trend towards a trial x group ($p=0.07$) interaction was observed, suggesting that the timing of peak displacement and peak velocity events differed between the groups over the course of Acquisition.

However, post-hoc tests failed to distinguish any differences. No other main effects or interactions involving group assignment were observed.

It is worth noting that a trend towards a joint x trial interaction ($p=0.065$) emerged, suggesting that the relative phase shift between the movement of the platform and the movement of the body at each landmark tended to differ. Post-hoc analysis using an adjusted alpha ($\alpha/2$) failed to elucidate significant differences.

Significant differences were observed in between joints, regardless of group assignment, as was demonstrated by a main effect for joint ($p<0.013$). This indicated that regardless of group, the discrete relative phase, that is, timing between joint movements, differed between joint linkages (Figure 4.4c). Post-hoc analysis using a corrected alpha ($\alpha/2$) failed to discern differences between the trials, but there was a trend ($p=0.051$) for the relative phase of the ankle/knee linkage to be greater than the knee/hip linkage (Figure 4.4c).

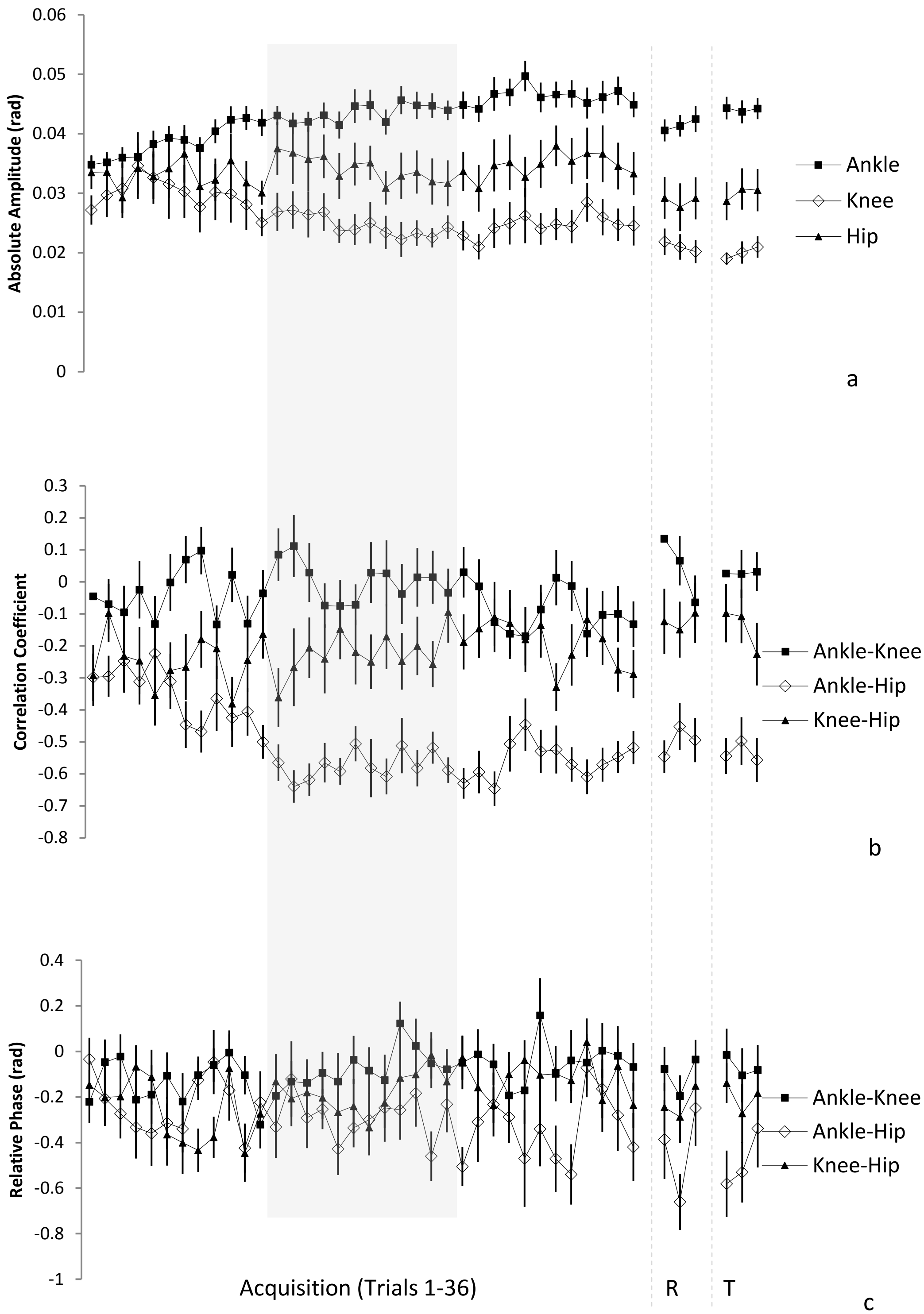

Figure 4.4 Measures of postural performance for joints and joint-linkages for each trial during the Acquisition, Retention (R), and Transfer (T) phases. Data is collapsed over group. (a) MAA for each joint (b) IC for each joint-linkage and (c) DRP for each joint-linkage.

4.2.2 Inferring Learning - Transfer & Retention

Figures 4.5(a-c) represent the MAA, IC, and DRP of landmarks and Figures 4.6(a-c) illustrates the joints and joint-linkages for the Trained, Retention, and Transfer phases. Trials were collapsed to form a single measure for each landmark, joint and joint linkage for Trained, Transfer and Retention phases. Table 4.2 provides a summary of main effects and interactions for learning analysis.

	l	l x g	p	p x g	l x p	l x p x g	g
MAA Landmarks	***	0.066					
IC Landmarks	***	**		0.075			
DRP Landmarks	***	*	0.088				

	j	j x g	p	p x g	j x p	j x p x g	g
MAA Joints	***		**	0.098			
IC Joint-linkages	***		**				
DRP Joint-linkages	**						

Table 4.2: Summary table of main effects and interactions for measures for learning comparisons. Trends with p-values below 0.01 are included for informational purposes. l – landmarks, j – joint or joint-linkage, g – group, p - phase. *** - p<0.001, ** - p<0.01, * - p<0.05.

MAA of landmarks (ankle, knee, hip, COM, shoulder, head). Figure 4.5a demonstrates the MAA for landmarks during the Trained, Retention, and Transfer phases. A trend towards a landmark x group interaction (p = 0.066) suggested that MAA differed at landmarks, and this difference was group dependent. Post-hoc follow up revealed a trend for a larger MAA at the head for the A group (p=0.069).

A main effect for landmark (p<0.001) confirmed that regardless of training condition, movement of the body differed with respect to location of the landmarks. Post hoc follow-up revealed that amplitude of movement at each landmark differed significantly ($p<0.01$), except between the hip and COM, though it trended towards significance ($p=0.054$). Mean amplitudes decreased between sequentially superior landmarks, with the largest amplitude of movement at the ankle, and the smallest at the head.

IC of the landmarks (ankle, knee, hip, COM, shoulder, head). A phase x group trend ($p=0.075$), depicted in Figure 4.5b, suggested that correlations may differ between phases and groups. Post hoc comparison between phases indicated that correlations were significantly greater ($0.83 \pm .069$ vs $0.73 \pm .097$) during the transfer phase for the A group ($p=0.018$). This significance must be taken with caution, however, given that the interaction was only trending towards significance. No other effects or interactions involving the testing phase emerged.

A landmark x group interaction ($p=0.002$) indicated that correlation between the translation pattern and landmarks differed based on group assignment. Post hoc follow up using an adjusted alpha ($\alpha/5$) indicated that movement of the head was much more correlated with the translation sequence in the A group ($0.62 \pm .18$) than the NA group ($0.39 \pm .22$; $p=0.018$).

DRP of the landmarks (ankle, knee, hip, COM, shoulder, head). Figure 4.5c demonstrates the DRP of landmarks for the Trained, Retention, and Transfer phases. A phase trend ($p=0.088$) was observed, suggesting that relative phase may have differed between testing periods. Post-hoc analysis failed to distinguish any differences between the phases, and no other main effect or interactions for phase existed.

A landmark x group interaction ($p=0.018$) revealed that regardless of training phase, the relative timing between the oscillating platform and body landmarks differed depending on training condition. Post hoc analysis using an adjusted alpha ($\alpha/5$) for multiple comparisons revealed a trend for a difference between shoulder phase ($p = 0.059$) and a significant difference between groups in relative phase at the head ($p=0.043$). In both cases, relative phase was less in the NA group than the A group.

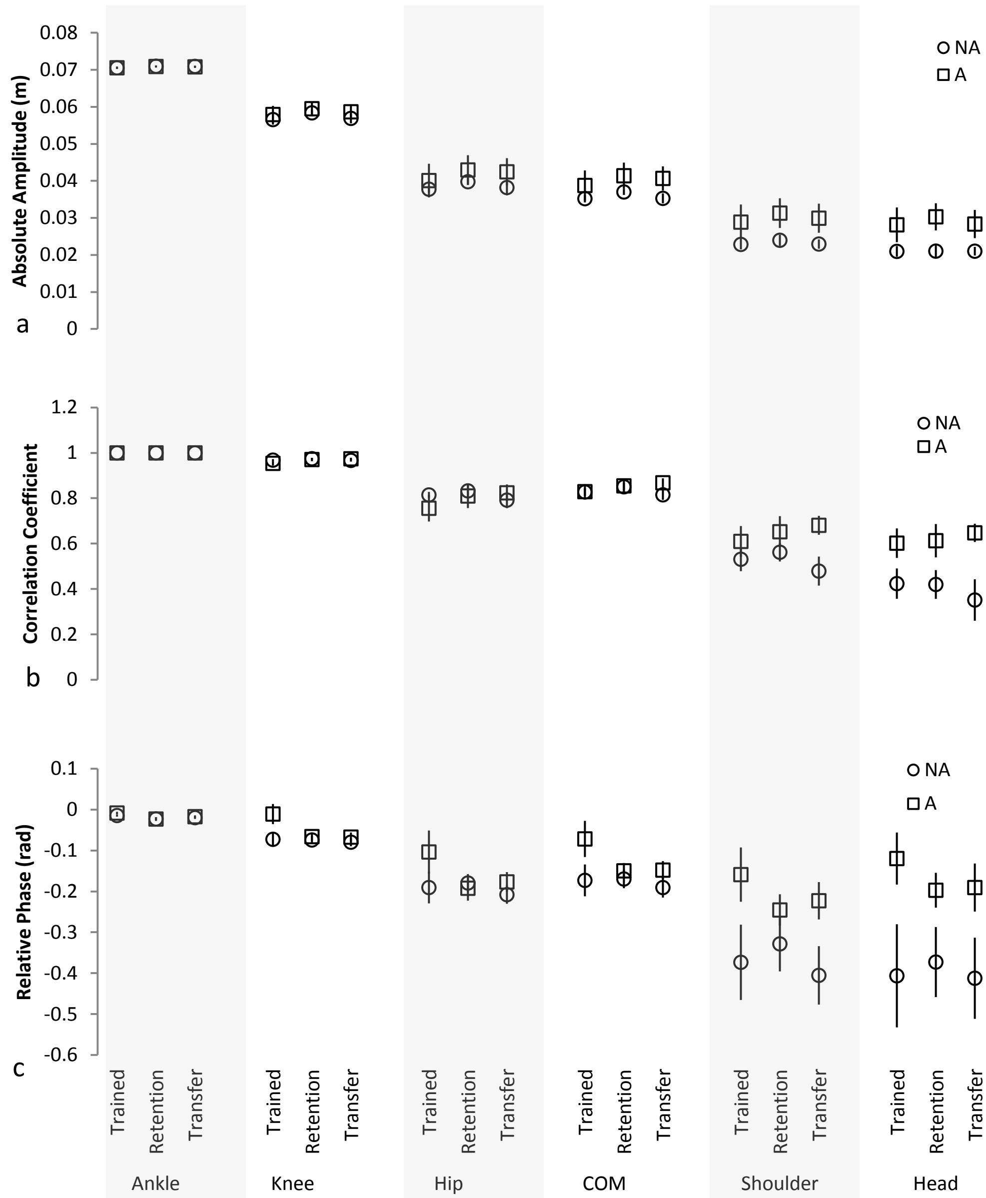

Figure 4.5 Postural performance measures for each landmark for the Trained, Retention, and Transfer phases. (a) MAA of landmarks (b) IC of landmarks (c) DRP of landmarks.

MAA of joints (ankle, knee, hip). Figure 4.6a represents the MAA for joints during the Trained, Retention, and Transfer phases. A main effect for phase (p=0.005) indicated that angular amplitudes differed between Training, Retention, and Transfer.

Post hoc comparison using an adjusted alpha (α/2) revealed that angular amplitudes were significantly different between Training and Retention phases (p=0.002), but not between Training and Transfer. Specifically, angular amplitudes were smaller in the Retention phase than during Trained phase (0.030 ± 0.002 rad vs 0.035 ± 0.002 rad, respectively). No other main effects or interactions were observed. A phase x group trend (p=0.098) was observed, but I did not follow up on this weak trend with post-hoc analysis.

A main effect for joint (p<0.001) indicated that regardless of phase or group assignment, the magnitude of angular rotation differed between joints. Post hoc comparison using an adjusted alpha (α/2) revealed that the amplitude was different between all joints. Angular amplitude at the ankle was 0.044 ± .002 rad, at the knee was 0.22 ± 0.002 rad, and at the hip was 0.031 ± .003 rad. It is worth noting that a slight trend towards a phase x group interaction (p=0.098) was observed during analysis.

IC of joint-linkages (ankle-knee, ankle-hip, knee-hip). A main effect for phase (p=0.001) indicated that correlations between the joint linkages differed between the Trained, Retention, and Transfer phases. Post hoc analysis revealed that there was a greater (p<0.025) negative correlation during the Trained phase than for both Retention and Transfer phases. The correlation coefficients were -0.295 ± .022 during the Trained phase, -0.202 ± .025 during the Retention phase, and -0.214 ± .031 during the Transfer phase. No other main effects or interactions for phase emerged.

A main effect for joint-linkage (p<0.001) indicated that correlations between joints differed with respect to joint-linkages, as represented in figure 4.6b. Post hoc comparison revealed that the correlation between the ankle and the hip had a much larger negative magnitude than the correlations of the other joint linkages (-0.537 ± 0.048; p<0.01).

DRP of joint-linkages (ankle-knee, ankle-hip, knee-hip). A main effect for joint-linkage (p=0.005) indicated that timing between joint linkages differed, and is demonstrated in figure 4.6c. Post hoc follow-up revealed that relative timing differed between the ankle-knee linkage and ankle-hip linkage (p=0.038). Mean relative phase of the ankle-knee linkage was -0.065 ± 0.069 rad, while relative phase of the ankle-hip linkage was -0.396 ± 0.094 rad. No other main effects or interactions were observed.

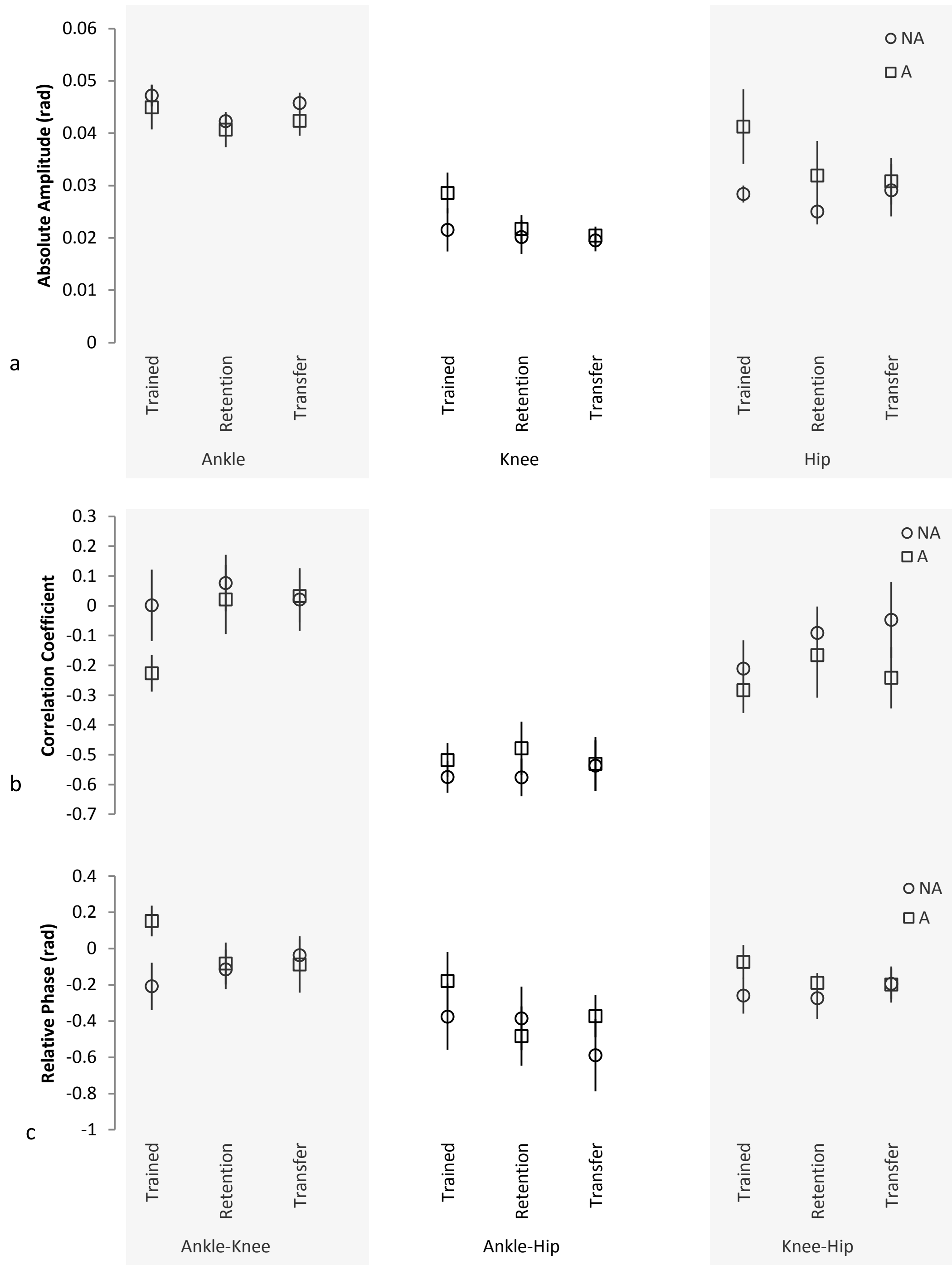

Figure 4.6 Performance measures for joints and joint-linkages during the Trained, Retention, and Transfer phases. (a) MAA for joints (b) IC for joint linkages (c) DRP for joint linkages

Chapter 5: Discussion

The purpose of this study was to investigate the effect of anxiety on motor learning. My study design was predicated on previous work in classical motor learning (Schmidt & Lee, 2005). It consisted of an Acquisition phase on Day 1 and Retention and Transfer tests on Day 2. Subjects stood on a platform that oscillated at 0.5Hz for 45 seconds in an Anterior-Posterior (A-P) direction during multiple training trials. The oscillation sequence consisted of random amplitudes for the first and last 15 seconds and 15 seconds of amplitudes in the middle segment that was repeated between each trial. The environment was manipulated to create two testing conditions that differed by perceived threat to balance. In accordance with the postural threat paradigm (Brown & Frank, 1997), I increased the perceived consequences of a fall or misstep by requiring subjects to stand on an elevated surface. Although the elevation in the anxious condition was only 9cm higher than the oscillating platform, there was an additional psychological effect in the fact that the pedestals were just large enough for each foot to stand comfortably on. In this way, a misstep in any direction would have required activation of balance recovery measures.

I have interpreted my key findings to imply that although motor learning did occur in both groups, the acquisition of optimal motor patterning and coordination strategy was impaired by anxiety about falling, and that these performance decrements were relatively permanent across both Non-Anxious (NA) and Anxious (A) environments. This interpretation is based on the observations that general movement of the body decreased regardless of training environment, but individuals who trained in an anxious environment were less effective in counteracting the specific movement of the translation sequence. Specifically, I found that both the NA and A groups showed reduced movement at each landmark as Acquisition (Aq) progressed (Fig. 4.2a), but the correlation between the movement of the platform and the movement of the head was stronger for the A group during late Acquisition (Trained), Retention, and Transfer phases (Fig. 4.5b). This finding indicates that the A group was less proficient in counteracting the effects of the translation sequence on the body, especially as more joints became involved.

There is a further possibility that training in the A condition resulted in reduced ability to Transfer the acquired skills to the NA environment, as suggested by the finding that movement of all landmarks in the Transfer test of the A group was more entrained with the translation sequence. These results, however, must be taken with caution as statistical significance in the main interaction was not met.

5.1 Confirmation of Anxiety

Aligned with similar studies employing the postural threat paradigm, anxiety was inferred by psychological arousal (Brown, et al., 2002; Brown, Polych, et al., 2006; L. A. Brown, Sleik, Polych, & Gage, 2002). Physiological arousal was determined by the response of the parasympathetic nervous system and measured using Galvanic Skin Conductance (GSC). Results from Day 1 revealed that GSC levels were higher in subjects who trained on the pedestal than those who trained on the platform. Increased physiological arousal was further confirmed in the A condition on Day 2 when subjects performed the postural task in both NA and A conditions. GSC was greater when subjects stood on the pedestal in comparison to when they stood on the platform (Figure

4.1). I have interpreted these findings to suggest that standing on the pedestal increased anxiety about falling.

5.2 Effects of Anxiety on Skill Acquisition

During the Aq phase, the mean amplitude of body landmarks decreased with practice. This decrease resulted in reduced A-P movement of the body in relation to the environment. This change was immediate (within four trials), occurred in both NA and A groups, and was maintained throughout the Aq phase. These findings are in line with Ko and colleagues (2003) who also reported significant increases in motor performance over the first three training trials. The observed change in amplitude during Aq was consistent regardless of training group, suggesting that this outcome represented a systematic improvement in motor performance.

The magnitude of the correlation between landmarks and the translation sequence differed between groups. Although this interaction did not reach significance in post hoc-testing, a trend suggested that the A group exhibited a stronger correlation between the movement of the head and the translation sequence than in the NA group. These finding suggest that the A group may not have been as proficient in preventing transfer of the platform movement to higher body segments in comparison to those who trained without anxiety.

The magnitude of oscillation between the joints tended to differ between the NA and A groups. Follow-up tests did not reveal any significance in this interaction, but visual inspection (Fig. 4.3d) suggested that compared to the A group, the NA group exhibited more movement at the ankles and less movement at the hip. Although these results must be examined cautiously, they point to the possibility of decreased rigidity at the hip and knee in the A group. Differences in the rigidity at the ankle and the hip joints implies a utilization of a motor strategy that was on the continuum between the “ankle mode” and “ankle-hip mode”, as outlined by Ko and colleagues (2001; Fig. 2.4).

In this case, increased movement at the ankle and decreased movement at the hip suggested that NA subjects adopted a motor pattern that was closer to the described “ankle-mode”. Conversely, the observed decrease in ankle movement and increased hip movement suggested the utilization of a motor pattern that included active involvement of the hip, such as the “ankle-hip mode”. Ko and colleagues (2001) reported that the “ankle mode” motor pattern was optimal for postural translations near 0.5Hz, while the “ankle-hip mode” is optimal for approximately 0.9Hz. The frequency of the postural translation was 0.5Hz in my study. As a result, I have taken these findings to infer that it is possible that the A group adopted a non-optimal motor pattern that included increased movement at the hip.

One of my hypotheses was that motor performance during skill acquisition would be reduced in conditions of increased anxiety about posture. I found that movement of the head in the A group tended to have a stronger correlation with the translation sequence than the NA group, and that rigidity of the knee and hip was also less in the A group compared with the NA group. Based on my reported findings, it is evident that performance during skill acquisition differed between groups. Previous findings in this field suggest that optimal postural response results in reducing the effect of the translation sequence on the body through the movement at each joint, a movement pattern that requires less rigidity and increased active involvement of the joints (Buchanan &

Horak, 1999; Ko, et al., 2001, 2003; Van Ooteghem, et al., 2008; Van Ooteghem, et al., 2010; Van Ooteghem, et al., 2009). Accordingly, I have interpreted my findings to infer that optimal motor performance during Acquisition was impaired in the A group compared to the NA group. To this end, imposed postural anxiety reduced motor performance during the Acquisition of a motor skill, thereby supporting my first hypothesis.

5.3 Effects of Anxiety on Skill Retention and Transfer

All subjects returned on Day 2 for Retention and Transfer assessments. Significant interactions between landmarks and groups indicated that training in an anxious condition affected postural performance in this oscillating postural task, and that these effects persisted over time. Similar to the Acquisition phase, the mean displacement amplitude of the head tended to be larger in the A group over all phases. Likewise, correlation of the head with the movement of the platform was significantly greater for the A group, suggesting that training under anxious conditions resulted in motor strategy that impaired the ability to decouple head movement from the movement of the platform. Results from the DRP also suggested that the timing of the oscillating landmarks differed as a result of the training environment. Individuals in the A group had relative phase measures of the head that were closer to zero, indicating that movement of the head was much more in-phase with the postural translation for the A group than for the NA group. These differences in motor outcomes between training groups were evident as trends during the Acquisition period, and I have interpreted these findings as evidence that the impairment of motor performance that was induced by training under conditions of anxiety are relatively permanent and persist over anxious and non-anxious environments.

No group differences emerged from analysis of the movement of the joints, suggesting that inter-joint coordination was similar between groups. Interestingly, regardless of group assignment, joint amplitudes were smaller in the Retention phase in comparison to the Trained phase and the magnitude of the joint-linkage correlations was greater in a negative direction in the Trained phase compared to both Retention and Transfer phases. These findings suggest that subjects adopted a posture that was more rigid and less coordinated during the Retention phase in comparison to the Trained phase.

Although subjects demonstrated a significant increase in ankle joint amplitude and ankle-hip coordination during Acquisition, my results indicate that motor performance on Day 2 decreased compared to performance levels attained by the end of practice on Day 1. It is possible that this performance difference represents retention loss (Schmidt & Lee, 2005, p. 442) rather than that a lack of learning. It is possible that this retention loss can explained by a warm-up decrement, whereby the observed reduction in performance is a result of a loss of set, that is, the loss of the transient mood or state that facilitated the motor skill (Schmidt & Lee, 2005, pp. 439, 448). Along these lines, motor performance would have resumed to past performance levels after a short practice session. Accordingly, I have not interpreted these findings as evidence that motor learning did not occur.

My results do, however, suggest that anxiety might affect the movement outcome when the task is performed in new, non-anxious environment. As evidence, the movement pattern of all landmarks in the A group during the Transfer phase was more entrained with the movement of the platform. Though this interaction did not reach statistical significance, post-hoc analysis of the movement did reveal significant differences. These findings imply that either the A group did not acquire the optimal motor pattern as effectively as the NA group or that they could not could not adapt and modify the acquired generalized motor pattern to the new context. Although movement patterns differed between the A and the NA group, I found no performance decrements between the groups within the Retention phase. This finding indicates that the acquisition of an optimal movement strategy was equivalent regardless of the anxious state of the training conditions. Accordingly, I have interpreted these findings to imply that the NA group may have been impaired in their ability to modify the acquired generalized motor pattern to the new, non-anxious context. These results, however, must be taken with caution because the level of significance for the main interaction did not meet the set criteria for differences.

I investigated the effect of anxiety on motor learning. My second hypothesis was that training in an anxious condition would reduce Retention of motor performance improvements in a balance relevant task. I reported an observed change in motor performance between the Trained and Retention phases, evidenced by decreased inter-joint correlation and increased joint amplitudes in the Retention phase compared with the Trained phase. However, these differences occurred regardless of induced anxiety during acquisition and could be reasoned as temporary or transient decrements. Furthermore, I observed motor performance decrements, including increased head movement in the A group compared with the NA group during the Trained, Retention, and Transfer phases. However, these decrements were previously evident in the Acquisition phase and were consistent over Training, Retention and Transfer phases, implying that these changes were a result of the impaired acquisition of an optimal motor pattern on Day one caused by anxiety about falling during the training. Moreover, these observed decrements were relatively permanent and persisted over both non-anxious and anxious environments. Accordingly, I found no evidence to support my second hypothesis, and must conclude that Retention of motor performance improvements is not impaired by motor skill acquisition conducted in conditions of increased anxiety.

My third hypothesis was that training under increased anxiety would reduce the ability to Transfer motor performance improvements to a non-anxious environment. I found that the movement of the body tended to be more entrained with the translation sequence for the A group than the NA group during the Transfer test, suggesting that subjects who trained in an anxious environment demonstrated reduced postural performance when transferring those skills to a new environment. My findings tended to support my hypothesis, and it is possible that inclusion of additional subjects may have provided greater significance and stronger support of my hypothesis.

5.4 Possible Mechanisms of Effect

My findings both support and contradict current research that investigates motor learning in anxious conditions. For instance, Oudejans and colleagues (2009; 2010) suggested that motor skill practice within an anxious environment can result in the acquisition of motor adaptations and self-regulatory processes that aid in reducing the negative effects of anxiety during subsequent performance of that task in anxious conditions. In my study, individuals who trained in a posturally anxious condition tended to exhibit differences in their movement outcomes that persisted into the next day and between testing environments. However, in contrast to the findings of Oudejans and colleagues, I interpreted the observed postural outcomes of the present balance task as an indicator that the acquisition of an optimal motor pattern was impaired because of the imposed anxiety.

As a possible explanation for this discrepancy, it could be that the measures I used were intended to assess postural coordination rather than gross success. I measured performance through the characterization of the movement patterns and whole-body responses involved in the balance task, whereas Oudjedans and colleagues focused on the success of the task goals. For instance, performance of the free-throw was measured by whether the basket was successful while the performance of dart throwing was measured by the proximity of the dart to the center of the target. It is plausible that an analysis of the motor patterns used for basketball shooting under anxious conditions might reveal a strategy that would be considered non-optimal. Based on their previous work, I suspect that Oudejans and colleagues (2009) would agree, as they suggested that task improvements that occurred while in an anxious condition were a result of self-regulatory processes. These self-regulatory processes could include increased effort (Eysenck & Calvo, 1992) and more effective strategies (Lewis & Linder, 1997), among other beneficial adaptive processes, that together help to improve performance during anxious conditions

The question still remains as to how the psychological effect of anxiety caused a reduction of motor performance improvements in the balance relevant task. One of the possibilities is that anxiety interfered with the allocation of the attentional resources that were necessary to achieve similar motor performance improvements as the NA group. It is established that postural control requires attentional resources (Shumway-Cook &

Woollacott, 2000), and that attentional resources are limited (Woollacott & Shumway-Cook, 2002). Furthermore, the process of motor learning is an attentionally demanding process (Passingham, et al., 1996; Wrisberg & Shea, 1978), particularly during the early, cognitive stage of learning (Posner & Keele, 1973, p. 813).

Eysenck's Attentional Control Theory (2007) postulates that anxiety negatively affects attentional control. This effect is caused in part by preoccupation with the threat that consumes limited attentional resources, thereby reducing attentional resources that are available for the task. In the present study, I measured only the physiological response to the anxious condition and did not assess worry or preoccupation with the threat. However, based on the protocols of this task, it is assumed that subjects were concerned with maintaining their stance on the pedestals, and that this worry contributed to the anxiety. Accordingly, one possible mechanism of action is that the induced anxiety interfered with attentional capacity, resulting in reduced attentional resources that were available for the sensory and motor integration needed in motor learning.

An implication from this line of reasoning is that impairment of motor learning that has occurred as a result of diminished attentional resources may affect balance training efforts in the elderly. It has been reported that postural control in the elderly requires a greater attentional demand compared to younger adults (Chiviacowsky, Wulf, & Wally, 2010; Doumas, Rapp, & Krampe, 2009; Huxhold,. Li, Schmiedek, & Lindenberger, 2006; Jamet, et al., 2007; Yogev-Seligmann et al., 2010). Given that anxiety reduces the amount of available attentional resources for balance tasks, the increased requirements for attentional resources in the elderly may not be effectively met, thereby further reducing motor learning capacity.

5.5 Conclusion

In this thesis, I have investigated the effect of anxiety on motor learning of a balance relevant task. I have reported an observed decrement in the acquisition of an optimal motor pattern that was relatively permanent and persisted in both non-anxious and anxious conditions, as well as a tendency for reduced ability to transfer improvements in motor performance to another environment. I have interpreted these findings as evidence that anxiety impairs motor learning during a balance relevant task.

These findings have a clinical application in that the effectiveness of balance training programs may be compromised by the presence of a fear of falling because of an inability to acquire optimal motor strategies. Furthermore, it remains a possibility individuals with high levels of anxiety might not demonstrate as much real-world benefit from training as their non-anxious peers. As such, efforts to alleviate fear of falling and anxiety in the elderly population may contribute to better training outcomes resulting in fewer falls in the elderly.

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Appendix A

Validation of a Modified Postural Threat Paradigm

Appendix A: Validation of a Modified Postural Threat Paradigm

My thesis investigated the effect of anxiety on learning during an continuous oscillating balance relevant task. It was necessary to create an environment of induced anxiety. A common means to induce anxiety during a postural motor task is by requiring the subject to perform the task while standing at the edge of an elevated platform, thereby increasing the perceived consequences of injury should a fall or balance failure occur. Previous work in this field indicated that positioning the subject at the edge of the platform was integral to eliciting an anxious response (A. L. Adkin, et al., 2000, 2002).

I was limited to a Neurocom SMART Equitest® system to produce the fore-aft oscillations in my study. The Neurocom® contains an embedded platform in the center of its 1.2m x 1m base, and as such, positioning a subject at the edge of the oscillating platform was not possible. As such, it was necessary to modify the postural threat paradigm such that my subjects still perceived an increased risk of falling. I tested the possibility that standing with each foot on 9cm high pedestals which were slightly larger than the feet. In this manner, a slip or misstep during the challenging task would have resulted in the need to activate balance recovery measures. This psychological constraint and additional risk is expected to increase anxiety.

In this preliminary study, I investigated whether standing on a pedestal could induce anxiety about falling during an oscillating balance relevant task.

Methods

Twelve healthy university students voluntarily participated in this study. The protocols of this study were approved by the Human Ethics Committee at the University of Lethbridge, Lethbridge, Canada.

Protocol

Participants completed 3 trials each of static standing and oscillating perturbations while standing directly on the platform, and 3 trials each of static standing and oscillating perturbations while standing on the pedestals, resulting in twelve trials. All twelve trials were fully randomized for each subject. All trials were 45 seconds in length and the oscillating perturbation trials consisted of pseudo-random amplitudes at a fixed frequency of 0.5Hz. The amplitudes of the first and last 15 seconds were random, while the amplitudes of the middle 15 seconds were a repeated pattern that was consistent between every subject and trial. The maximum amplitude possible using this equipment was ±6.35cm.

Measures. I inferred anxiety by measuring physiological arousal using Galvanic Skin Conductance (GSC). Subjects wore Ag-AgCl sensors on their middle and ring fingers of their left hand to record physiological arousal. I also asked subjects two questions after each trial:

1. Balance Confidence (BC): “On a scale of 0 to 100, how confident were you in your ability to maintain your balance, where 0 is not confident at all and 100 is extremely confident? “

2. Fall Anxiety (FA): "On a scale of 0 to 100, how anxious were you about falling, where 0 is not anxious at all and 100 is extremely anxious?"

Data Processing. The time-based linear trend was removed from the GSC values of the sample trials using a custom written Matlab® program. The first trial was used as a baseline reference value, and the mean of the first trial was removed from all subsequent trials for that participant.

Results

Questionnaires. I performed a three-way MANOVA (2 condition x 2 task x 3 trials using both BC and Anxiety as dependent variables. A main effect for condition ($p = 0.007$), task ($p = 0.001$) and trial ($p = 0.020$) were observed. There were also condition x task ($p = 0.011$) and task x trial ($p = 0.009$) interactions. Univariate follow up on each of the dependent variables indicated that there was a main effect for condition (BC, $p = 0.001$; FA, $p = 0.027$), Task (BC, $p < 0.001$; FA, $p = 0.002$), and Trial (BC, $p = 0.027$; FA, $p = 0.002$). The interactions for condition x task (BC, $p = 0.002$; FA, $p = 0.026$), and task x trial (BC, $p = 0.025$; FA, $p < 0.001$) were also significant. This data is presented in Figures 1 and 2.

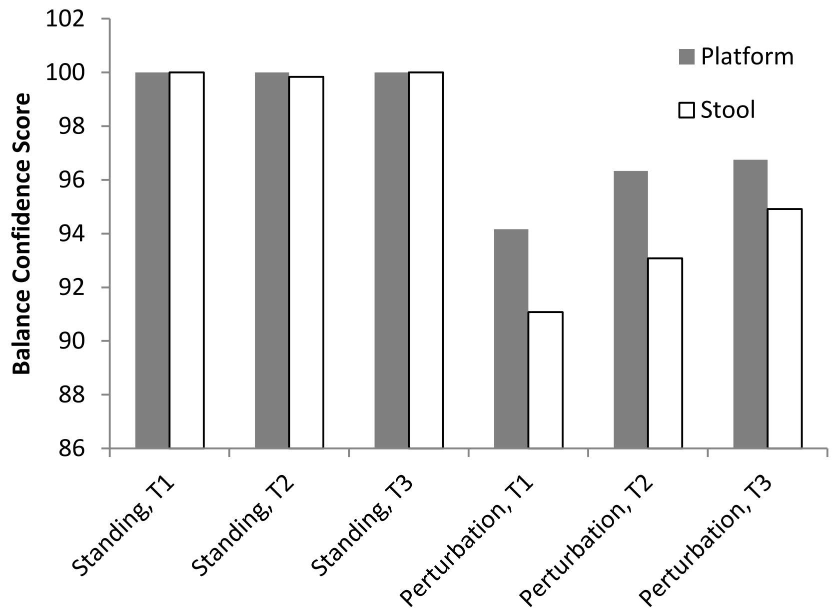

Figure 1. Balance Confidence scores for each condition and trial, delineated by group.

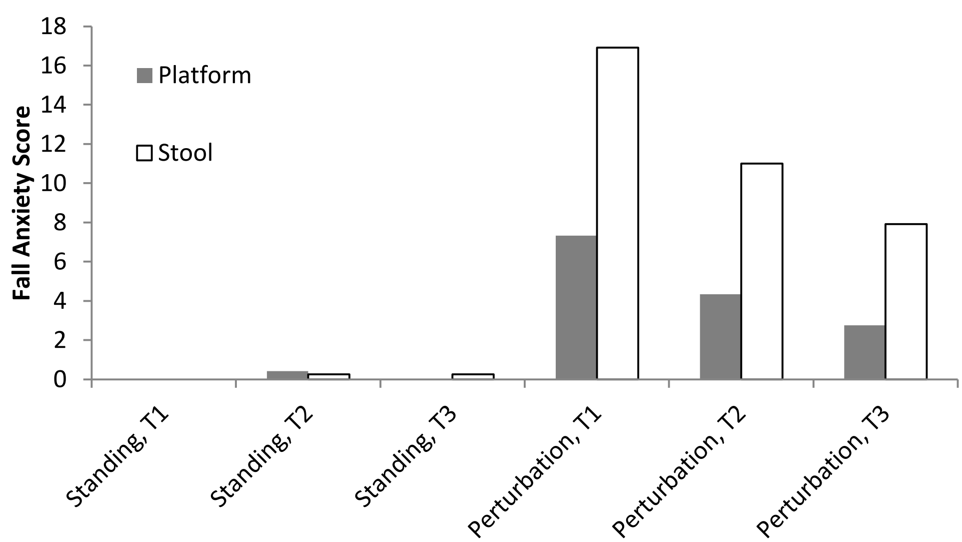

Figure 2. Fall Anxiety scores for each condition and trial, delineated by group.

GSC. I performed a three-way ANOVA (2 condition x 2 tasks x 3 trials) of the mean, detrended GSC. There was a main effect for condition ($p = 0.004$) and task ($p < 0.001$).

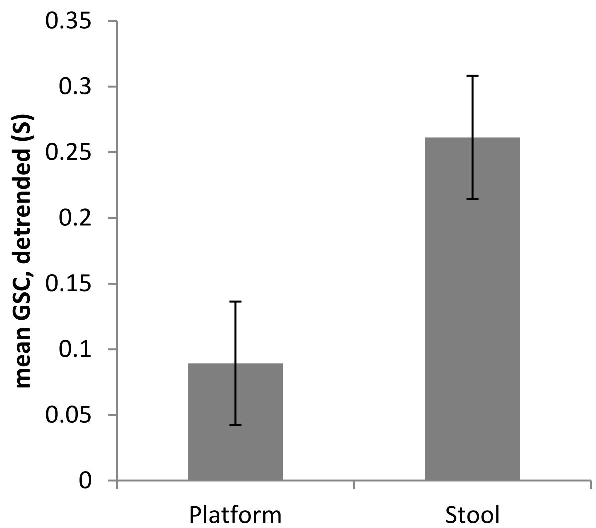

Figure 4. Mean GSC for platform and pedestals (stool) conditions, collapsed over group and trial.

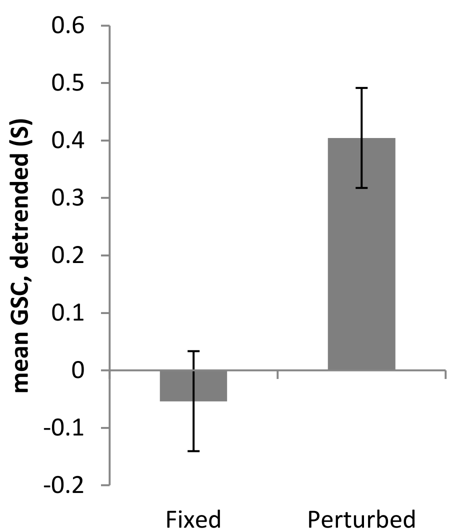

Figure 5. Mean GSC between the standing (fixed) and perturbation trials, collapsed over group and trial.

Discussion:

My results suggest that subjects produced a physiological and psychological response that varied dependent on task and condition. I have interpreted my findings to indicate that anxiety was increased when subjects completed the oscillating balance task while standing on 9cm high pedestals that were slightly larger than the subject’s feet. As such, I found that among healthy university students, simple 9cm pedestals could be employed to induce anxiety about posture during an oscillating balance task in a research setting. This modified threat paradigm could be used in place of the traditional postural threat paradigm when equipment and facilities prevent its use. The applicability of this modified paradigm in older adults, pathological populations, fall fearful, and clinical settings has yet to be investigated.