Can Attention Focus Instructions Reduce the Effects of Fatigue on Balance Control?

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ABSTRACT

Localized muscular fatigue has been identified to have detrimental effects on balance control, an important skill for everyday life. Manipulation of attention focus instructions has been shown to benefit performance of various motor skills including balance and has been found to facilitate endurance during fatiguing tasks. The purpose of this thesis was to determine if the use of attention focus instructions could attenuate the effects of muscular fatigue on balance control. Twenty-four participants performed a balance task (two-legged stance on an unstable platform) before and after a fatigue protocol. Trunk sway, platform excursions, and lower limb muscle activity was measured. Results suggest that use of either internal or external attention focus instructions can reduce the immediate effects of muscular fatigue of the lower limb on balance control as shown through reduced trunk sway and platform excursions. These results have relevance for individuals performing balance tasks in a fatigued state.

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CHAPTER ONE: LITERATURE REVIEW

1.1 Balance Control

Balance is an important requirement for the performance of many of our activities of daily living ranging from standing on a chair to reach for an item located in a high cupboard to walking home from a store carrying a bag of groceries through a crowded street. The control of balance is a complex sensorimotor process that involves the integration of information from multiple sensory systems (i.e., visual, vestibular, and somatosensory) in order to generate appropriate motor responses to maintain upright stance and prevent falling (Horak 2006). Specifically, this challenging process requires an individual to be able to control their centre of mass (COM) within their base of support (BOS) whether that BOS is stationary (i.e., as would occur during quiet stance) or moving (i.e., as would occur during walking). The COM can be defined as an imaginary point around which the total body mass is equally distributed (Winter 1995). The BOS can be defined as the area of the body that comes in contact with the environment (i.e., supporting surface on which one stands) and allows for ground reaction forces to be generated in order to control the movement of the COM (Winter 1995). The central nervous system (CNS) must make constant and precise adjustments in order to control the COM within a stationary BOS (i.e., when the COM moves within the BOS when standing) or moving BOS (i.e., when the COM moves outside of the BOS with each step during walking). The centre of pressure (COP) can be defined as the location of the weighted average of the sum of vertical ground reaction forces and most often is examined in the anterior-posterior (A-P) direction and the medial-lateral (M-L) direction. The COP reflects the generation of stabilizing ankle torques (i.e., adjustments in the A-P direction) and lateral weight shifts (i.e., adjustments in the M-L direction) to control the body COM and as such the COP provides an indication of the CNS response to control COM movement.

Many factors have been shown to influence balance control. These factors may be physiological (e.g., reduced lower limb muscle strength; Wolfson, Judge, Whipple & King 1995), emotional or psychological (e.g., fear of falling; Davis, Campbell, Adkin & Carpenter 2009), or cognitive (e.g., attention; Woollacott & Shumway-Cook 2002). Furthermore, interactions between multiple physiological, psychological or cognitive factors can lead to confounding effects on balance control. The effects of these factors can be more pronounced when performing difficult tasks (i.e., one legged stance, obstacle avoidance, balance recovery) or when performing in challenging environments (i.e., navigating through a cluttered room).

One important cognitive factor that has been shown to influence balance control is attention. For example, divided attention protocols (i.e., dual-task situations where individuals perform a concurrent task while maintaining balance) have been shown to impact balance control (Woollacott & Shumway-Cook 2002). Attention focus or "where" an individual directs their attention when completing a task has also been shown to modify balance control (Wulf 2007). This thesis will examine attention focus and its effects on motor skill performance, specifically balance control, and whether instructions related to attention focus can modify the influence of a specific factor (i.e., muscle fatigue) that has been shown to influence balance control. First, the literature on the effects of attention focus on motor skill performance, and more specifically balance control, will be reviewed. This will be followed by a review of the literature on the effects of muscle fatigue on balance control in order to demonstrate its efficacy as a model to show balance differences in order to examine whether specific attention focus can minimize these fatigue-related effects on balance.

1.2 Attention Focus

Attention focus can be defined as "where" an individual directs their attention when completing a task. When studying attention focus, two main focus types are compared. One type is an internal attention focus which refers to instructions that are given to direct the performer's attention towards their body's action. A second type is an external attention focus which refers to instructions provided to direct the performer's attention towards the effects of their motions. In studies examining the effects of attention focus on motor skill performance, these types of attention focus are often compared to a control condition where no specific attention focus instructions are given as to where the individual is to focus during the performance of the motor skill.

An example of the type of attention focus instructions given can be observed in the following study. Wulf, Hob & Prinz (1998, Exp 1) examined the effect of attention focus instructions on ski-simulator performance. All participants were told the goal of the tasks was to move with the largest possible amplitude of movement. Participants were placed in an internal attention focus group with further instructions to complete the task by trying to exert force on their outer foot, an external attention focus group with additional instructions to complete the task by exerting force on the outer wheels of the ski-simulator, or a control group with no additional attention focus instructions given. Comparisons were made between attention focus groups to determine which type of instruction benefited the outcome measure of interest. In this study, the external attention focus group compared to the internal attention focus or control groups showed superior performance and learning of this task.

Studies examining the manipulation of the type of attention focus in numerous motor skills, including skills required for golf (Wulf, Lauterbach & Toole 1999), basketball (Zachry, Wulf, Mercer & Bezodis 2005), and soccer and volleyball (Wulf, McConnel, Gartner & Schwarz 2002) have found that the adoption of an external attention focus leads to both increased motor performance and learning compared to the use of either an internal attention focus or control conditions in which no specific instructions are given as to where to focus during task performance. A summary of the literature illustrating this consistent observation is presented in Table 1.

The constrained action hypothesis was forwarded by Wulf, McNevin & Shea (2001) to explain this phenomenon. It states that the adoption of an internal attention focus constrains the motor system as it interferes with automatic control processes that would normally regulate movement. In turn by adopting an external attention focus, it allows for more automatic control of movement which produces more effective and efficient performance. As individuals traditionally perform similarly under internal attention focus conditions and control (i.e., no instruction) conditions, it has been suggested that by default individuals attempt to consciously control movement (i.e., adopt an internal attention focus, Wulf 2007).

Table 1

Effects of Attention Focus on Various Motor Skills.

Research Study	Motor Skill	Focus	Results
Wulf et al. (1998, Exp. 1)	Ski-simulator	EF, IF, C	EF > IF = C
Wulf et al. (1998, Exp. 2)	Stabilometer	EF, IF	EF > IF
Wulf et al. (1999)	Golf pitch shot	EF, IF	EF > IF
Wulf et al. (2001)	Stabilometer	EF, IF	EF > IF
Wulf et al. (2002, Exp. 1)	Volleyball serve	EF, IF	EF > IF
Wulf et al. (2002, Exp. 2)	Soccer kick	EF, IF	EF > IF
Totsika & Wulf (2003)	Pedalo	EF, IF	EF > IF
Vance et al. (2004)	Biceps curls (movement economy)	EF, IF	EF > IF
Landers et al. (2005)	Balance Master	EF, IF, C	EF > IF = C
Zachry et al. (2005)	Basketball free throw	EF, IF	EF > IF
Laufer et al. (2007)	Biodex Stability System	EF, IF	EF > IF
Wulf et al. (2007) Exp 2	Balance on inflated rubber disk	EF, IF, C	EF > IF = C
Wulf et al. (2007)	Jump-and-reach	EF, IF, C	EF > IF = C
Marchant et al. (2009)	Isokinetic elbow flexions (torque)	EF, IF	EF > IF
Wulf & Dufek (2009)	Jump-and-reach	EF, IF	EF > IF
Wulf et al. (2009)	Balance on inflated rubber disk	EF, IF, C	EF > IF = C
Chiviacowsky et al. (2010)	Stabilometer	EF, IF	EF > IF
Wulf et al. (2010)	Jump-and-reach	EF, IF	EF > IF
Lohse & Sherwood (2011)	Wall-sit	EF, IF	EF > IF

Note: EF=external attention focus, IF=internal attention focus, C=control

1.2.1 Effects of Attention Focus on Balance Control

As shown in Table 1, investigations into the effects of attention focus have also shown that the adoption of an external attention focus benefits the performance and learning of various balance tasks. Wulf et al. (1998, exp 2.) examined the effects of external and internal attention focus on learning to balance on a stabilometer. In this task, performers were instructed to focus either on keeping their feet at the same height (i.e., an internal attention focus) or on keeping two markers placed on the stabilometer at the same height (i.e., an external attention focus). During the retention test, when no attention focus instructions were given, the group that adopted an external attention focus during practice showed a superior ability to maintain the board in a horizontal position compared to the internal attention focus group.

Subsequent investigations into the differential effects of attention focus instructions on balance tasks ranging from quiet standing (Wulf, Tollner & Shea 2007, Landers, Wulf, Wallmann & Guadagnoli 2005), to stabilometer use (Wulf et al. 2001; Chiviacowsky, Wulf & Wally 2010), to standing on inflatable rubber disks (Wulf et al. 2007; Wulf, Landers, Lewthwaite & Tollner 2009), to performance on the biodex stability system (Laufer, Rotem-Lehrer, Ronen, Khayutin & Rozenberg 2007) to pedalo use (Totsika & Wulf 2003) have found similar results showing both increased performance, retention and ability to transfer to novel tasks while adopting an external attention focus compared to either an internal attention focus or no explicitly directed attention focus.

Additionally, although the majority of this work has focused on healthy young adults, a benefit to balance performance from adopting an external attention focus on has been observed for older adults (Chiviacowsky et al. 2010), for individuals recovering from lateral ankle sprains (Laufer et al. 2007), ACL replacement (Gokeler et al. 2014) and for individuals with Parkinson's

Disease (Landers et al. 2005; Wulf et al. 2007) or Multiple Sclerosis (Shafizadeh, Platt & Mohammadi 2013)

1.2.2 Effects of Attention Focus on Force Production and Neuromuscular Activity

The effects of adopting a different type of attention focus have also been examined at the neuromuscular level. Vance, Wulf, Tollner, McNevin & Mercer (2004) examined electromyographic (EMG) activity of individuals performing biceps curls while adopting an internal attention focus (i.e., on the movement of their arms) or an external attention focus (i.e., on the movement of the curl bar). The results of this study showed that when adopting an external attention focus individuals displayed greater movement economy at the neuromuscular level as demonstrated by lower integrated EMG levels in the agonist biceps and antagonist triceps during the motion reflecting greater inter-muscular coordination. Additionally, at least initially, while adopting an external attention focus, individuals recruited fewer motor units while completing the task, as shown by lower EMG mean power frequency (MPF) values, despite being required to exert the same amount of force in all conditions. Also of note, when given no instructions as to the timing of movements, individuals performed the motions quicker when adopting an external attention focus.

To examine if these differences in EMG activity observed in the above study also resulted in improvement in different outcome measures, Zachry et al. (2005) measured the EMG activity of the dominant arm while individuals performed basketball free throws. When asked to focus internally on the snapping motion of their wrist or externally on the center back of the rim, participants not only exhibited greater accuracy while focusing externally but also generated lower levels of EMG activity in the biceps and triceps. These findings confirm that the alterations in patterns of neuromuscular activity occur concurrently with changes in outcome measures.

One outcome measure of particular note that has been found to increase with the adoption of an external attention focus is that of force production. Marchant, Greig & Scott (2009) examined the effects of attention focus on an individual's force production during elbow flexion. These authors found that when focusing externally participants were able to produce significantly larger maximal voluntary contractions (MVC). The results hold true for tasks requiring whole-body coordination as it has been shown that the use of an external attention focus during a maximum vertical jump task results in an increase in force production as well as corresponding increases in maximum jump height (Wulf, Zachry, Grandas and Dufek 2007; Wulf and Dufek 2009). Further exploration of the vertical jump task by Wulf, Dufek, Lozano & Pettigrew (2010) found that despite the increases observed in jump height and force production, individuals who adopted an external attention focus also exhibited lower levels of EMG activity in the leg muscles while still maintaining the same muscle onset times throughout the task.

More recently, Lohse & Sherwood (2011) have examined the effects of attention focus on the completion of a fatiguing motor task. In their study, individuals performed a physically demanding wall sit task; participants were required to sit with their backs against a wall with their knees and hips bent to 90 degrees with no additional support. Participants were required to maintain this position for as long as possible. When performing this task, individuals were provided with different attention focus instructions. One group of individuals was instructed to focus internally with the instruction "to keep the thighs parallel to the ground". Two other groups of individuals were instructed to focus externally. One external attention focus group was given the instruction "to keep the imaginary line between markers attached to their knee and hip parallel to the ground" and the second external attention focus group was given the instruction "to keep the imaginary line between the tops of two pylons parallel to the ground". It was found that both external attention focus conditions resulted in significantly longer times to fatigue (i.e., voluntary exhaustion or task failure) as well as lower ratings of perceived exertion. This study suggests that an external attention focus may benefit tasks that involve muscular fatigue by producing better performance (i.e., longer times to failure). Further support to the benefits of instructions to adopt an external focus on muscular endurance was observed by Marchant, Greig, Bullough & Hitchen (2009). In their study, individuals were able to perform significantly more repetitions of bench press and back squat at 75% of their one repetition maximum while instructed to adopt an external focus with the instructions "Focus on moving and exerting force through and against the bar" compared to individuals provided with the internal instructions "focus on moving and exerting force with your arms" or control groups who were given no specific attention focus instructions. With this is mind, it is also possible that the use of attention focus instructions may help minimize potential fatigue effects on balance control. An understanding of whether or not this is possible is important due to the well-established effects of fatigue on balance control.

1.3 Effects of Fatigue on Balance Control

There are a number of different ways to generate muscle fatigue. Research has examined general muscular exercise such as running, cycling, etc. (i.e., exercises typically involving whole body movement) and found resulting changes in balance control (Paillard 2012). Research has also examined the effects of localized muscular fatigue (LMF). LMF refers to the fatigue of a specific muscle group and can be considered as "the failure to maintain the required or expected force" (Edwards 1981) or as "any exercise induced reduction in the capacity to generate force or power output" (Vollestad 1997) in that specific muscle group. The effects of LMF on balance control have been explored for a range of specific muscle groups (i.e., ankle musculature, hip musculature, lumbar extensors, etc.), fatigue protocols (i.e., isometric contractions, isokinetic contractions, etc.), and balance tasks (i.e., single leg stance, two-legged stance, balance recovery from external perturbations, etc.; Paillard 2012). This thesis will examine the effects of LMF on balance control, specifically focusing on LMF of the ankle muscles.

1.3.1 Ankle Musculature Fatigue

Investigations into the effects of LMF of the ankle musculature on balance control have employed a wide variety of balance tasks and fatigue protocols. Table 2 shows that fatigue of the plantar-flexors, dorsi-flexors, or invertors and evertors results in increased balance adjustments during both single and two-legged quiet stance. Table 3 shows that fatigue of the plantar-flexors, dorsi-flexors, or invertors and evertors results in increased balance adjustments during both single and two-legged stance during dynamic balance tasks such as standing on an unstable support surface and balance recovery following an external perturbation

Table 2

Effects of LMF of the Plantar-Flexors on Static Balance.

Study	LMF	Balance Task	Vision	Results
Lundin et al. (1993)	PF/DF	SL	EO	↑ A-P & M-L COP sway Anterior weight shift following fatigue
Yaggie & McGreggor (2002)	PF/DF/Invertor/evertors in succession	SL	EO	↑ M-L COP sway, ↑ A-P sway on forward lean test
Alderton & Moritz (2003)	PF (dominant leg only)	SL (dominant & non-dominant leg)	EO	↑ in A-P & M-L trunk acceleration ↑ A-P COP amplitude
Caron (2003)	PF	DL	EO	↑ COP velocity
Corbeil et al. (2003)	PF	Tandem	EO, EC	↑ A-P & M-L COP velocity, mean frequency for EO & EC
Gribble & Hertel (2004a)	PF/DF,	SL	EO	↑ A-P COP velocity
Gribble & Hertel (2004b)	Evertors/Invertors,	SL	EO	No effect
Bellew & Fenter (2006)	PF/DF	FR, LERT, SLSTT (EC)	EC	↓ SLSTT
Dickin & Doan (2008)	PF/DF,	SL	EO	↑ A-P & M-L RMS of the COP
Bizid et al. (2009)	PF,	SL	EC	↑ M-L COP velocity
Lin et al. (2009)	PF	DL	EC	↑ A-P COP-COM amplitude
Bisson et al. (2010)	PF	SL, DL, Semi-tandem	EO, EC	↑ A-P, M-L COP velocity for all stances ↑M-L COP amp in SL, EC only
Boyas et al. (2011)	PF, DF, PF/DF	SL	EO, EC	↑COP total area, A-P COP velocity for all EO ↑A-P COP velocity for PF & PF/DF with EC
Gimmon et al. (2011)	PF	DL firm surface & DL on foam	EC	↑ A-P COP amp, A-P & M-L COP velocity on both surfaces ↑ total sway area on foam

Note for muscles fatigued, muscles separate by a "/" (i.e. PF/DF) indicates multiple muscle groups fatigued simultaneously. When muscle groups are separated by a comma this indicates separate experimental groups. PF = plantar-flexors, DF = dorsi-flexors, EO = eyes open, EC = eyes closed, SL = Single leg stance, DL = Two-Footed stance. FR = functional reach. LERT = lower extremity reach test. SLSTT = single leg stance time test. RMS = root mean squared.

Table 3

Effects of LMF of the Plantar-Flexors on Dynamic Balance.

Study	LMF	Balance Task	Vision	Results
Miller & Bird (1976)	PF	Dynobalometer	EO	No effect of time in balance
Kwon et al.(1998)	PF/DF	SL on KAT balance system	EO	↓ balance index scores
Salavati et al.(2007)	PF/DF, evertors/invertors,	SL on Biodex Stability System	EC	↑ APSI, MLSI & OSI
Reimer & Wikstrom (2010)	PF	SL on Biodex Stability System	EO	↑ APSI, MLSI, OSI following ankle
Kennedy et al. (2012)	PF/DF	DL on perturbation platform	EO	COP position shifts and alterations in muscle onset times

Note for muscles fatigued, muscles separate by a "/" (i.e. PF/DF) indicates multiple muscle groups fatigued simultaneously. When muscle groups are separated by a comma this indicates separate experimental groups. PF = plantar-flexors, DF = dorsi-flexors, EO = eyes open, EC = eyes closed, SL = Single leg stance, DL = Two-Footed stance. APSI, MLSI and OSI are stability indices that are specific to the Biodex Stability System, increases in these reflect poorer balance control.

Bisson, Chopra, Azzi, Morgan & Bilodeau (2010) found isometrically induced plantar-flexor fatigue resulted in not only increased A-P and M-L velocity and total sway of the COP during single leg stance with both eyes open and closed but also increased M-L amplitude of COP adjustments when the eyes were closed. Alderton, Mortiz & Moe-Nilssen (2003) examined the balance effects of fatiguing a single leg only on single leg stance of the fatigued or non-fatigued leg. They found that following fatigue, stance on either leg resulted in increased M-L & A-P trunk acceleration, A-P amplitude of excursions of the COP and decreased M-L velocity of the COP. Stance on the fatigued leg also showed increased M-L COP amplitude and decreased A-P velocity of COP movements. In contrast Bizid et al. (2009) found no effect on COP velocities during single leg stance with vision after isokinetically fatiguing the plantar-flexors to less than 50% of their original MVC.

Boyas et al. (2011) compared the effects of isokinetically fatiguing either the plantar-flexors or dorsi-flexors to when both muscle groups were fatigued simultaneously. To examine this, participants completed three separate testing sessions during which they fatigued either the plantar-flexors only, dorsi-flexors only, or the plantar-flexors and dorsi-flexors together. In each session the muscle group(s) chosen was fatigued isokinetically until unable to produce 50% of their pre-fatigue peak torque. Following fatigue, balance control was examined through a two legged stance task with and without vision. The authors found degradations in balance control emerged via increased total sway and A-P velocity of the COP as well as a posterior shift in the average position of the COP following all three fatigue protocols. However, increases were found to be significantly greater in all measures following the simultaneous plantar-flexor and dorsi-flexor fatigue compared to fatiguing either muscle group on its own. Of note is that the resulting decrements in balance control were only observed when balance was assessed with vision removed. In contrast to these findings, isokinetically induced LMF of the plantar-flexors and dorsi-flexors together has shown effects on balance control when vision is present (Lundin, Feuerbach & Grabiner 1993; Gribble & Hertel 2004ab; Bellew & Fenter 2006; Dickin & Doan 2008).

Lundin et al. (1993) found that consecutively fatiguing the dorsi-flexors then plantar-flexors in a blocked format through isokinetically performed concentric-eccentric contractions resulted in increased amplitudes of A-P and M-L movements of the COP in addition to an anterior shift in mean position of the COP when standing on one leg with the eyes open. Gribble & Hertel (2004a) simultaneously fatigued the plantar-flexors and dorsi-flexors in an isokinetic manner until less than 50% peak torque could be produced in both directions. Following fatigue, increases occurred in the velocity of A-P movements of the COP but not in the M-L direction during single leg stance with eyes open. Dickin & Doan (2008) examined simultaneous isokinetic fatigue of the plantar-flexors and dorsi-flexors; this time fatigue was defined as an inability to produce 70% MVC in both directions. Furthermore the stance task was performed on both a normal and sway referenced surface. Following fatigue, increases were observed in the amplitude variability of COP movements in both the A-P and M-L directions. These findings were consistent across both surface conditions. Bellew & Fenter (2006) further showed the effects of simultaneous isokinetic fatigue of the plantar-flexors and dorsi-flexors through decreases in the single leg stance time test and functional reach scores of older women who were fatigued to <50% peak torque in both muscle groups. Poorer scores on both of these measures are interpreted as decreases in balance control.

Examinations into the effects of LMF of the invertors and evertors on balance control are less clear. Gribble & Hertel (2004b) isokinetically fatigued the invertors and evertors simultaneously to <50% peak torque and found no effect on the velocity of COP movements during single legged stance with vision. Yaggie & McGreggor (2002) however, found increased M-L and total sway of the COP during single leg stance with vision along with increased A-P sway on a forward lean test following successive isokinetically induced fatigue of the invertors, evertors, dorsi-flexors and plantar-flexors to <50% peak torque. It must be noted however that the results seen in that study may in fact be due to the fatigue of the plantar-flexors and dorsi-flexors rather than that of the invertors and evertors.

Research investigating the effects of LMF of the ankle musculature on balance control during two legged stance have focused solely on LMF of the plantar-flexors. Caron (2003) found isometrically induced fatigue of the plantar-flexors to result in increased velocity and standard deviations of A-P movements of the COP during two legged stance with eyes open. Bisson et al. (2010) showed similar results in that isometric plantar-flexor fatigue caused increased A-P & M-L velocity of COP movements with the eyes either open or closed, as well as increased total sway area when tested with the eyes open. Lin et al. (2009) elicited fatigue of the plantar-flexors of the dominant leg via isotonic contractions until participants were unable to produce 60% of their MVC. When fatigued they found this to result in increased COP-COM difference measures in the A-P direction during two legged stance with the eyes closed. The difference between COP and COM has been found to be highly correlated to horizontal COM movements and can be interpreted as the "error" of the balance control system (Lafond, Duarte & Prince 2004), increases in this measure reflect poorer balance control. Finally, Gimmon, Riemer, Oddsson & Melzer (2011) examined two legged stance on both firm and foam surfaces following concentric-eccentric contractions of the plantar-flexors performed to volitional fatigue. Fatigue was found to result in increased amplitude of A-P sway of the COP, A-P and M-L velocities of the COP, and total sway of the COP on both surfaces

Investigations into the effects of LMF of the plantar-flexors on balance control during tandem stance have compared the effects of fatigue both with and without vision. Bisson et al. (2010) found that isometrically fatiguing the plantar-flexors by requiring participants to rise to their toes and hold this position as long as possible resulted in increases in the A-P sway amplitude as well as A-P and M-L sway velocities of the COP with eyes either open or closed. Corbeil, Blouin, Begin, Nougier & Teasdale (2003) also found no interaction between LMF of the plantar-flexors elicited via 100 weighted heel raises and visual conditions. Their results demonstrated increases in mean A-P and M-L sway velocity, maximum instantaneous A-P sway velocity, and mean and median frequency of sway of the COP following fatigue regardless of the availability of visual information.

Several studies have looked at the effect of LMF of the ankle musculature on balance control during dynamic balance tasks. Miller & Bird (1976) fatigued either the plantar-flexors or dorsi-flexors through weighted concentric-eccentric contractions to volitional fatigue and found no effect of either protocol on time spent in balance (i.e., horizontal) on an unstable support surface during subsequent 60 seconds trials. However Kwon, Choi, Yi & Kwon (1998) using an unstable platform found that simultaneous isokinetic fatigue of the plantar-flexors and dorsi-flexors to less than 50% peak torque resulted in increased deviations from the horizontal position of the platform and characterized this as poorer balance performance. Reimer & Wikstrom (2010) found increased A-P, M-L and overall deviations on an unstable platform to arise following weighted calf raises. Similar results were found by Salavati, Moghadam, Ebrahimi & Arab (2007) following simultaneous isokinetic fatigue of the plantar-flexors and dorsi-flexors or invertors and evertors. One point of difference is that Salavati et al. (2007) found that combined invertor and evertor fatigue created significantly larger increases in the M-L direction compared to combined plantar-flexor and dorsi-flexor fatigue.

When compared to unperturbed stance, limited research has been conducted to investigate the effects of LMF on balance recovery following external perturbations. The research that has been conducted has shown a number of significant changes in balance recovery strategies and muscle activation patterns when fatigued.

Kennedy, Guevel & Sveistrup (2012) simultaneously fatigued the plantar-flexors and dorsi-flexors of participants through alternating isometric contractions until both muscles were unable produce 50% MVC. Following this, participants were required to stand with feet shoulder width apart and eyes open on a perturbation platform that oscillated 20 cm in the A-P direction at a frequency of 0.25-0.5 Hz. Following the fatigue protocol, increased co-activation of the tibialis anterior and medial gastrocnemius was observed. Additionally, during forward perturbations the tibialis anterior and rectus femoris were activated earlier. Upon examination of reactions during backward perturbations, two subgroups emerged. The first was characterized by an increase in the amplitude of displacements of the COP with an accompanying decrease in biceps femoris activity.

The second group exhibited a decrease in the amplitude of displacement of the COP along with earlier medial gastrocnemius onset times and higher levels of tibialis anterior – medial gastrocnemius co-activation compared to the COP increase subgroup.

Davidson, Madigan, Nussbaum & Wojcik (2009) investigated the effect of LMF of the plantar-flexors on balance recovery to forward external perturbations in both young and older adults. LMF was elicited using concentric weighted contractions of the plantar-flexors until <70% MVC could be produced. Fatigue was found to cause increases in peak amplitude and velocity of the displacement of the COM, and decreased amplitude of displacements of the COP in both groups. Additionally the older group was found to have an increased time to return to within 20% of the peak COP displacement following perturbation which can be interpreted as a slower recovery rate to the perturbation.

1.3.2 Fatigue of Other Muscle Groups

As with the ankle musculature, varying protocols have also been used to examine the effects of LMF of the neck extensors(Schieppati, Nardone & Schmid 2003, Gosselin, Rassoulian & Brown 2004) trunk extensors (Davidson, Madigan & Nussbaum 2004; Vuillerme, Anziani & Rougier 2007; Lin et al. 2009, Cetin, Bayramoglu, Aytar, Surenkok & Yemisci 2008, Wilson, Madigan, Davidson & Nussbaum 2006, Davidson et al. 2009), abdominals (Miller & Bird 1976), hip musculature (Miller & Bird 1976, Reimer & Wikstrom 2010, Salavati et al. 2007, Gribble & Hertel 2004a,b, Bellew et al. 2009), and knee musculature (Lin et al. 2009, Bizid et al. 2009, Chaubert & Paillard 2012, Gribble & Hertel 2004a, Dickin & Doan 2009, Bellew & Fenter 2006, Kwon et al. 1998, Miller & Bird 1976) on postural control. In general it has been found that LMF at these additional sites results in similar decrements in balance control as those found to result from LMF of the ankle musculature.

1.3.3 Duration of Fatigue Effects

An important factor that must be taken into consideration when examining the effects of LMF on balance control is the time course of the effects of fatigue on balance control. Recovery rates from the fatigue protocol and thus the disturbance to balance can vary widely depending on the nature of the fatigue protocol. For example; the duration of the fatigue protocol, the muscles fatigued and their corresponding muscle fiber composition, the nature of the muscle actions performed to elicit fatigue (i.e., concentric compared to eccentric), and the percentage of strength loss that was induced, can all affect the time course of resulting balance disturbances (Paillard 2012). Taking this into consideration, the resulting disturbance to balance following LMF has been found to persist from 2 minutes (Boyas et al. 2011) to 30 minutes (Dickin & Doan 2008) following the completion of the fatigue protocol depending on the specific protocol used. Given the time course of fatigue effects on balance control, most studies have aimed to perform post fatigue postural evaluations as soon as possible following the fatigue protocol (i.e. 30-60 seconds; Salavati et al. 2007; Boyas et al. 2011; Gimmon et al. 2011). Alternatively, some studies that examine multiple attempts of balance trials post fatigue will repeat the fatigue protocol before each trial or set of balance trials to ensure that the appropriate fatigue level is present at the time of each measurement (Boyas et al. 2011).

From this review of literature, it can be seen that a number of different muscle groups (i.e., ankle musculature, lumbar extensors, etc.), fatigue protocols (i.e., isometric contractions, isokinetic contractions, etc.), balance tasks (i.e., single-legged stance, two-legged stance, unstable surfaces, etc.), have been utilized by researchers examining the effects of LMF on balance. Despite these varied methodologies, in most cases, increased amplitude and velocity of COP adjustments have been shown post compared to pre fatigue, which reflects poorer balance control. The majority of work has focused on the ankle musculature and thus for the purpose of this thesis it was proposed to isolate LMF of the ankle plantar-flexors and examine balance on an unstable support surface.

CHAPTER TWO: RATIONALE, PURPOSE, AND HYPOTHESES

2.1 Rationale

The use of different attention focus instructions can influence balance performance and learning. Specifically, an external attention focus instruction which directs attention to the effects of one's movement can benefit this type of motor skill performance compared to an internal attention focus instruction which directs attention to the mechanics of one's movement or no attention focus instructions (Wulf, 2007).

LMF has been shown to have a negative influence on balance control as reflected by greater postural instability when fatigued (Paillard, 2012). Thus, this manipulation or system perturbation can be used to generate a change in how the CNS controls balance (i.e., pre compared to post fatigue conditions).

There is evidence to suggest that an external attention focus compared other instructional sets can produce longer times to fatigue in a wall sit task (Lohse & Sherwood, 2011). Thus, this same type of instruction may help to minimize the negative effects of fatigue on balance control. The results of this thesis are important to assist in developing specific instructional sets to improve balance performance for those individuals who perform balance tasks under fatiguing conditions (i.e., industry) or for those individuals who have balance problems and may fatigue more easily during performance of activities of daily living.

2.2 Purpose

The purpose of this thesis was to determine if attention focus instructions modify the effects of LMF on balance control. More specifically, this thesis aimed to determine if the adoption of an external attention focus reduced the effects of fatigue on balance control when standing on an unstable support surface (i.e., tilt-board) compared to the adoption of an internal attention focus or no specific attention focus instructions (i.e., control condition).

2.3 Hypotheses

For all attention focus groups (external, internal, control), it was expected that LMF would negatively influence balance control. This negative effect would be shown by an increased amplitude variability of tilt-board excursions, greater trunk pitch and roll sway, and decreased frequency of lower leg muscular activity in the post-fatigue compared to pre-fatigue condition. However, it was hypothesized that these fatigue effects would be significantly less for those individuals who were instructed to adopt an external attention focus compared to those individuals who were instructed to adopt an internal attention focus or those individuals who received no specific attention focus instructions at all, especially immediately post-fatigue (i.e., initial post-fatigue trials).

CHAPTER THREE: METHODOLOGY

3.1 Participants

Twenty-four healthy young adults volunteered to participate in this thesis study (15 male, 9 female; age = 21.29 ± 1.989 years). Participants were excluded from the study if they had any current self-reported musculoskeletal, neurological or sensory disorder that could affect their ability to complete either the balance task or the fatigue protocol. Each participant after being informed of all experimental procedures provided written consent prior to the start of testing. All experimental procedures were reviewed and given ethical clearance by the Brock University research ethics board (Appendix A).

3.2 Balance Task

Participants were required to maintain their balance for 30 seconds on an unstable support surface (i.e., tilt-board) that could move passively up to 19 degrees in both the anterior and posterior direction. Each participant completed 12 familiarization trials, followed by five pre-fatigue trials and five post-fatigue trials. Prior to the first familiarization trial, participants stood on the tilt-board and established a comfortable foot position within a stance width defined by their foot length. Once this stance position was determined, it was marked on the tilt-board to ensure consistent foot position for all experimental trials. For the duration of each trial, participants were required to look straight ahead at a visual target that was placed at eye level 1.15 m in front of them. The starting position (Figure 1) for each trial had the participant hold two hand rails that were placed on each side of the board to ensure that the tilt-board was in a horizontal position (approximately zero degrees). Participants were then given a “go” signal at which point they released contact with the hand rails and attempted to maintain their balance for 30 seconds. At the end of each trial, participants were instructed to step off of the tilt-board and received approximately 30 seconds before commencement of the next trial.

Figure 1. Apparatus for the Balance Task. Note that the participant is standing in the initial start position holding the handrails.

3.3 Attention Focus Instruction Conditions

Participants, stratified by sex, were randomly assigned to an external attention focus group (n = 8), an internal attention focus group (n = 8), or a control attention focus group (n = 8). The instruction provided to all participants, independent of group, was to "attempt to maintain your balance as best as you can". This common instruction was provided before the 12 familiarization trials, at the start of the five pre-fatigue trials and prior to the start of the five post-fatigue trials. Only the external and internal attention focus groups were given additional instructions as to how to attempt to maintain balance prior to the start of the post-fatigue trials. The external attention focus group was provided with the added instruction “by minimizing movements of the board to keep it in a horizontal position”. While the internal attention focus group was given the added instruction “by minimizing movements of your feet to keep them horizontal to the ground”. The control attention focus group received no additional instructions regarding how to maintain balance. The instructional sets used by all three groups are summarized in Table 4.

Table 4

Attention Focus Instruction sets for the External, Internal, and Control Attention Focus Groups.

Attention Focus Group	**Common Instruction**	**Additional Instructions**
External	Attempt to maintain your balance as best as you can	By minimizing movements of the board to keep it in a horizontal position
Internal		By minimizing movements of your feet to keep them horizontal to the ground
Control		None

Note. The common instructions provided to each group as well as the specific instructions provided to the external and internal attention focus groups on how to maintain balance.

3.4 Fatigue Protocol

The fatigue protocol was designed to bilaterally generate LMF of the ankle musculature, specifically the plantar-flexors. Participants were required to perform heels raises to the beat of a metronome set to a speed of 60 beats per minutes. Participants were instructed to time each heel raise so the apex of the heel raise occurred in time to the beat. Prior to beginning the fatigue protocol, the proper method to perform the heel raises was demonstrated to ensure the movement was isolated to the ankle joint. Participants were provided encouragement throughout the protocol to ensure maximum effort was given. The fatigue protocol continued until the participant voluntarily stopped or were unable to continue performing the heel raises. A similar fatigue protocol has been used in past research (Vuillerme & Biosgontier 2008). Immediately following cessation of the heel raises, participants were required to provide a rating of perceived exertion according to the Borg 15-point RPE scale (Appendix B). The total duration of the fatigue protocol was recorded for each participant.

3.5 Experimental Procedure

A flowchart outlining the experimental procedure is presented in Figure 2. Upon arriving at the laboratory, the letter of intent and informed consent was explained to each participant. Once informed consent was provided, participants completed a brief health questionnaire (Appendix C), and demographic and anthropometric measures were recorded (i.e., age, sex, height and weight) Next, the balance task was explained to the participant. Participants were given the common instruction and completed 12 familiarization trials following which they were provided with five minutes of seated rest. The familiarization trials were completed in an attempt to eliminate the effect of practice on the pre-fatigue balance trials. Following the seated rest, participants completed five pre-fatigue trials. Following these five trials, participants completed the fatigue protocol. After the completion of the fatigue protocol, participants in the external and internal attention focus groups were provided with added instructions while participants in the control group received no added instructions. Next, participants completed five post-fatigue trials. It is important to note that all participants began the post-fatigue trials within 60 seconds of completing the fatigue protocol. Following the completion of the post-fatigue trials, participants in the external and internal attention focus groups reported on a scale from 0% (not at all) to 100% (all the time) the amount that they used the attention focus instructions provided (Appendix D) Participants in the control group reported where they had focused their attention during the post-fatigue trials in response to an open ended question (no attention focus source was provided).

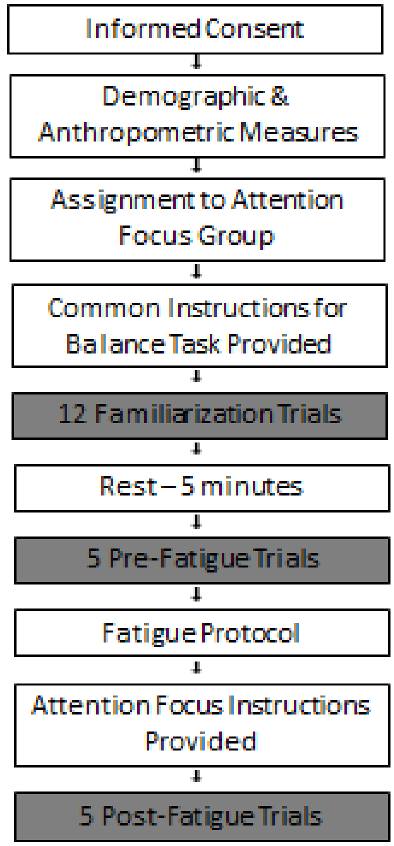

Figure 2. Experimental Procedure. Note that the common instructions were provided and reinforced prior to each block of trials (familiarization, pre-fatigue, post-fatigue) and added attention focus instructions were provided prior to the post-fatigue trials for the external and internal attention focus groups only.

3.6 Dependent Measures

Balance performance was assessed by monitoring the movement of the tilt-board, the movement of the trunk, and the electromyographic activity of the lower leg muscles (i.e., tibialis anterior, medial gastrocnemius). The total duration of all balance trials was 30 s. However, all summary measures were calculated only on the last 25 s of the trial to avoid any balance adjustments that may have occurred when releasing the handrails.

The tilt-board was outfitted with an inertial measurement unit (VN-100 rugged, Vectornav Technologies, Richardson, Texas) which electronically measures the angular displacement of the tilt-board in voltage where 1 volt was equal to 4.096 degrees of movement. This signal was measured at a rate of 1000 Hz and recorded using the commercially available software (Windaq, DATAQ Instruments Inc., Akron, Ohio). The root mean square (RMS) of the signal was calculated using algorithms in Matlab (Mathworks, Natick, Massachusetts) to provide a summary measure to determine the amplitude variability of movements of the tilt-board in the anterior-posterior direction. Greater amplitude variability of tilt-board movements reflected greater postural instability.

Movement of the trunk was measured through the use of two angular velocity transducers (SwayStar System, Balance Int Innovations GmbH, Switzerland). Participants wore the lightweight device that contained the transducers (<2 kg) at the lumbar level of the back (L2-L3) and the device was attached via an elasticized motorcycle belt (Figure 3) The transducers were oriented so that one measured movement in the roll direction (side-to-side), whereas the other measured movement in the pitch direction (forward-to-backward). Peak-to-peak range excursions in roll and pitch directions for both trunk angular displacement (with respect to reset angular positions of zero displacement at the start of each task, degrees) and trunk angular velocity (degrees/s) were calculated. Thus, four summary measures were calculated: pitch angle, pitch angular velocity, roll angle, and roll angular velocity. Greater trunk pitch and roll angle and angular velocity values reflected greater postural instability.

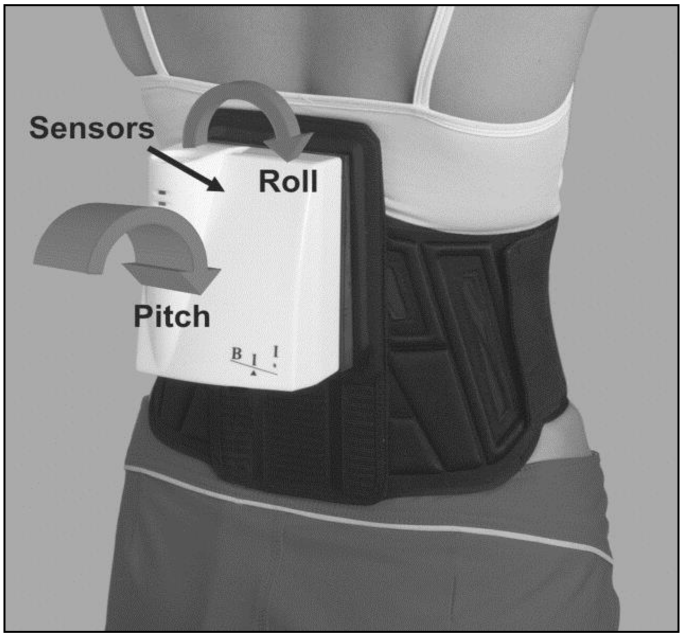

Figure 3: Participant Wearing the Trunk Sway Monitoring System (SwayStar System, Balance Int Innovations GmbH, Switzerland). Note that one sensor is oriented to measure trunk movement in the roll (side-to-side) and pitch (forward-to-backward) direction.

Electromyographic (EMG) was measured via double differentiated surface electrodes placed on the tibialis anterior (TA) and medial gastrocnemius (MG) of both legs according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) Project recommendations for EMG sensor placement for each muscle.

Prior to electrode placement the skin was shaved, lightly abraded and cleaned with alcohol to limit skin-electrode impedance. The EMG signal was sampled at 1000 HZ and recorded with commercially available software (Windaq). Using algorithms in Matlab, a spike analysis was performed on each signal. A spike consists of a both an upward and downward deflection, each of which crosses the isoelectric line (Gabriel, Basford & An 2001). This analysis was completed through the following steps. A baseline measure activity was collected in the 2 seconds immediately prior to the commencement of each balance trial. The root mean square amplitude of this period was used as the noise threshold as the level above which the signal must pass to be considered a spike. This threshold was adjusted upwards by a value of 1-3 standard deviations for each signal. The magnitude of the adjustment necessary was determined through visual inspection of each signal to ensure that only periods of distinct muscular activity crossed this threshold. The signal was then filtered with a fourth order Butterworth filter at 400 Hz. In the filtered signal all instances in which a pair of upward and downward deflections passed the noise threshold were recorded as a spike. The amplitude of each spike was calculated by adding the difference between the maximum amplitude of the spike and the start of the upward inflection with the difference between the maximum amplitude of the spike and the end of the downward deflection and dividing the resultant value by 2. The average amplitude of all spikes occurring across each trial was then calculated giving the magnitude measure of mean spike amplitude. Additionally the total number of spikes occurring across each trial was also recorded. This analysis was performed separately on each signal examining the final 25 seconds of each balance trial.

Measures of mean spike amplitude have been found to change quite similarly to RMS amplitude while mean spike frequency (total number of spikes) behaves similarly to EMG mean power frequency (Gabriel et al. 2001) and have been shown to be highly reliable during dynamic contractions (Gabriel 2000). Based on this, it was expected that during dynamic contractions mean spike amplitude would increase with fatigue while total number of spikes would decrease with fatigue (Potvin & Bent 1997).

To determine the consistency of the fatigue protocol, two dependent measures were obtained. First, participants were asked to rate their perceived exertion (RPE) using the Borg 15-point scale (range 6-20). RPE are a report of exercise intensity and have been found to correlate highly to blood lactate and heart rate, with higher values equating to increased intensity (Scherr et al. 2012).Second, the time (in seconds) it took for each participant to reach the point at which they could no longer continue the fatigue protocol was measured by recording the duration from the onset of the fatigue protocol (i.e., first heel raise) to the end of the fatigue protocol (i.e., last heel raise completed).

3.6 Statistical Analysis

All statistical calculations were conducted on using commercially available software (SPSS version 20, Chicago, Illinois).

3.6.1 Rating of Perceived Exertion and Time to Fatigue Measures

Descriptive statistics were calculated for rating of perceived exertion and time to fatigue by attention focus group. A one-way analysis of variance (ANOVA) procedure with attention focus group (3 levels) as the between-subjects factor was performed for rating of perceived exertion and for time to fatigue. Significance level was set at $p < 0.05$ for these tests. If a significant main effect of attention focus group was found, post-hoc follow-up comparisons were conducted to determine which groups were different from each other.

3.6.2 Adherence to Attention Focus Instructions

Descriptive statistics were calculated for adherence to attention focus instructions for each attention focus group. A one-way ANOVA procedure with attention group (2 levels) as the between–subjects factor was performed for adherence to attention focus instructions. Significance level was set at $p < 0.05$ for this test.

3.6.3 Balance Measures

Descriptive statistics were calculated for all balance-related dependent measures by attention focus group (external, internal, control), by fatigue condition (pre- and post-fatigue) and by trial (1-5). There were 13 dependent measures: amplitude variability of the tilt-board, pitch angle, pitch angular velocity, roll angle, roll angular velocity, mean spike amplitude and total number of spikes for left and right TA and MG.

A 3 x 2 x 5 repeated-measures ANOVA was conducted with attention focus group (external, internal, control) as the between-subjects factor, and fatigue (pre-fatigue, post-fatigue) and trial (1-5) as the repeated factors for each balance-related dependent measure. For any significant main effect (i.e., attention focus group, trial) or two-way interaction, (i.e., attention focus group by fatigue, attention focus group by trial, or fatigue by trial) or three-way interaction (i.e., attention focus group by fatigue by trial), follow-up comparisons were made in order to inspect the nature of the significant effect. The level of significance was set at $p < 0.05$ for all of these analyses.

3.6.4 Assumptions

All assumptions for statistical analysis were examined. Prior to analysis all variables were screened for outliers. Dependent measures were converted to standardized z-scores and univariate outliers were identified by a z-score 3.29 standard deviations above or below the mean. Any variable fitting this criteria was replaced with a value ±3 standard deviations of the mean in the direction it was previously outlying. Following replacements the assumption was re-run for the dependent measure in question and any newly identified cases were replaced via the same method (Tabachnick & Fidell 2007). Normality was assessed through examination of z-scores of the skewness and kurtosis of each variable. Any values ± 3 standard deviations were considered significantly skewed or kurtotic. The assumption of normality was met for all dependent measures and to prevent any potential hindrance to the interpretation of the data the decision was made not to transform any potential outliers.

For the repeated measures ANOVAs, the assumption of sphericity was assessed using Mauchley's test. Any violations of this assumption were addressed by correcting the degrees of freedom using the Huynh-Feldt estimate of sphericity.

CHAPTER 4: RESULTS

4.1 Participants

Demographic and anthropometric variables for each attention focus group are presented in Table 5. There were no significant differences in age, height or weight between attention focus groups. Note that there was an equal distribution of males and females within each attention focus group.

Table 5

Means and (Standard Deviations) for Age, Height, and Weight for each Attention Focus Group

Variables	Control (n=8, 5M, 3F)	External (n=8, 5M, 3F)	Internal (n=8, 5M, 3F)
Age	21.0 (2.07)	21.6 (2.2)	21.3 (1.9)
Height (cm)	175.8 (3.1)	175.4 (10.7)	190.9 (31.1)
Weight (kg)	81.1 (9.9)	75.6 (14.2)	74.3 (12.6)

4.2 Borg Rating of Perceived Exertion and Time to Fatigue

The results revealed no significant difference in the Borg Rating of Perceived Exertion between attention focus groups [$F(2, 23) = 2.519$, $p = 0.105$]. The mean Borg Rating of Perceived Exertion for each attention focus group is presented in Figure 4. The results also showed that there was no significant difference in the time to fatigue between attention focus groups [$F(2, 23) = 2.831$, $p = 0.082$]. Figure 5 presents the mean time to fatigue for each attention focus group.

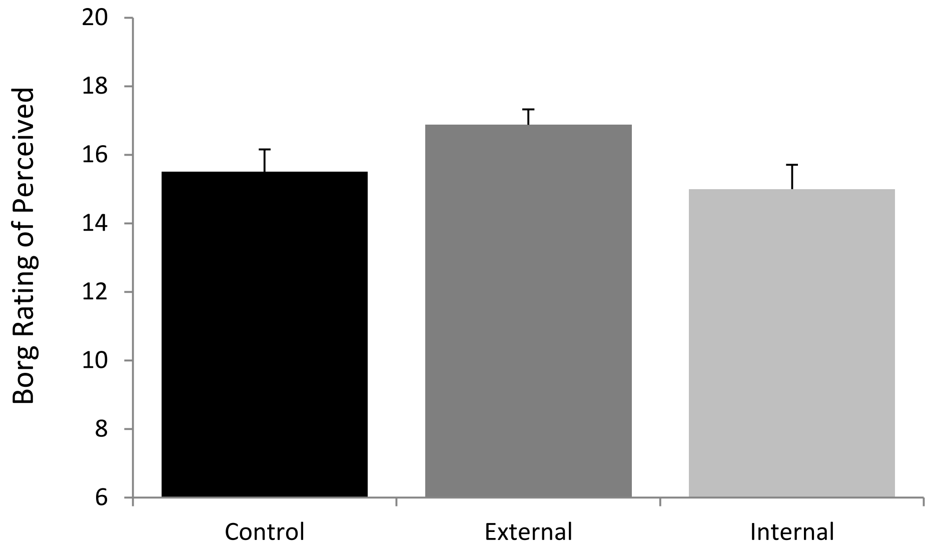

Figure 4. Mean Borg Rating of Perceived Exertion for each Attention Focus Group. Note that error bars reflect standard error of the mean values.

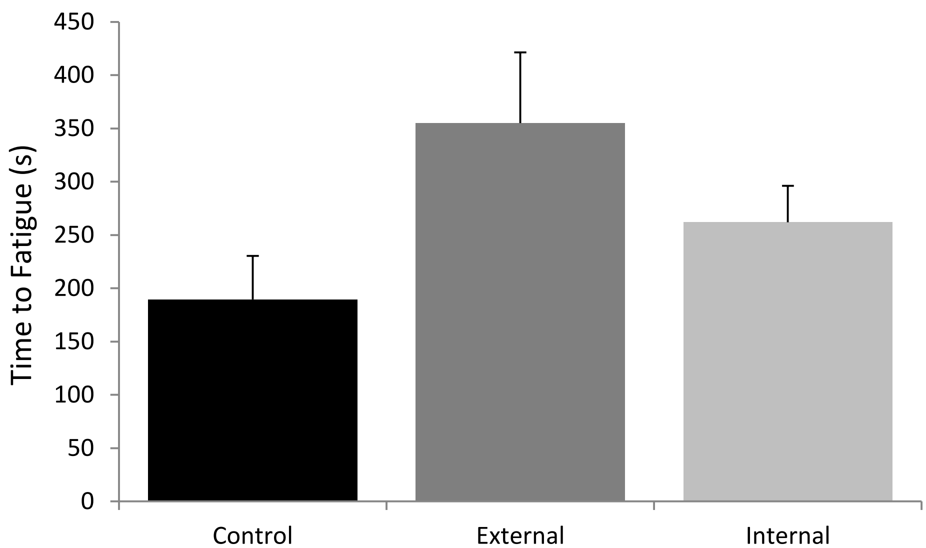

Figure 5. Mean Time to Fatigue for each Attention Focus Group. Note that error bars reflect standard error of the mean values.

4.3 Manipulation Check for Adherence to Attention Focus Instructions

The results did not reveal a significant main effect of attention focus group for self-reported adherence to instruction [$F(1,15) = 2.107$, $p = 0.169$]. Mean (and standard deviation) instruction adherence was 72.25 (8.59) % for the external attention focus group and 85.63 (3.33) % for the internal attention focus group

4.4 Trunk Sway

Table 6 presents the results of the 3 (attention focus group: control, external, internal) x 2 (fatigue: pre, post) x 5 (trial: 1-5) between and within-subjects ANOVA that was conducted for each of the four trunk sway variables (pitch angle, pitch velocity, roll angle, roll velocity).

Table 6

Probability Levels for the Main Effects, Two-way Interaction Effects, and Three-way Interaction Effect for the ANOVAs Conducted for Pitch Angle, Pitch Velocity, Roll Angle, and Roll Velocity

Effects	Pitch Angle	Pitch Velocity	Roll Angle	Roll Velocity
Attention Focus Group	.995	.600	.923	.227
Fatigue	**.003**	**<.001**	**.003**	**.001**
Trial	**.001**	**.001**	.142	.211
Attention Focus Group x Fatigue	.438	.441	.097	.184
Attention Focus Group x Trial	**.044**	.173	**.031**	**.018**
Fatigue x Trial	**.001**	**.022**	.070	**.033**
Attention Focus Group x Fatigue x Trial	.204	.129	.136	**.050**

4.4.1 Pitch Angle

Mauchley's test indicated that the assumption of sphericity had been violated for the main effect of trial ($\chi^2(9) = 44.512$, $p < 0.0001$) and the interaction effect between fatigue and trial ($\chi^2(9) = 29.889$, $p < 0.0001$) for pitch angle. To address the violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity.

The results revealed statistically significant main effects for fatigue [$F(1, 21) = 11.740$, $p = 0.003$, $\eta_p^2 = 0.359$] and trial [$F(2.244, 52.567) = 7.710$, $p = 0.001$, $\eta_p^2 = 0.269$] for pitch angle. The results also showed statistically significant interaction effects between attention focus group and trial [$F(4.488, 52.567) = 2.567$, $p = 0.044$, $\eta_p^2 = 0.196$] and between fatigue and trial [$F(2.503, 52.567) = 7.650$, $p =0.001$, $\eta_p^2 = 0.267$]. No other statistically significant main effects or two-way interaction effects were observed.

The results also did not reveal a statistically significant three-way interaction effect between attention focus group, fatigue, and trial [$F(5.006, 52.567) = 1.506$, $p =0.204$, $\eta_p^2 = 0.125$]. Although not statistically significant, given the purpose of the thesis and the underpowered nature of the design, the decision was made to further explore the three-way interaction between attention focus group, fatigue, and trial for pitch angle (Figure 6). Orthogonal polynomial testing for trial was conducted for pre-fatigue and post-fatigue conditions for each attention focus group. This follow-up analysis revealed a statistically significant trial effect for the post-fatigue condition for the control attention focus group [$F(4, 28) = 7.117$, $p < 0.001$, $\eta_p^2 = 0.504$]. The trend components observed for this trial effect were as follows: linear ($p = 0.050$, accounting for 44.9% of the variance), quadratic ($p = 0.018$, accounting for 44.3% of the variance), cubic ($p = 0.010$, accounting for 9.6% of the variance) and quartic ($p = 0.187$, accounting for 1.2% of the variance). No statistically significant trial effects were observed for the post-fatigue condition for the external or internal attention focus groups or for the pre-fatigue condition for external, internal, or control attention focus groups.

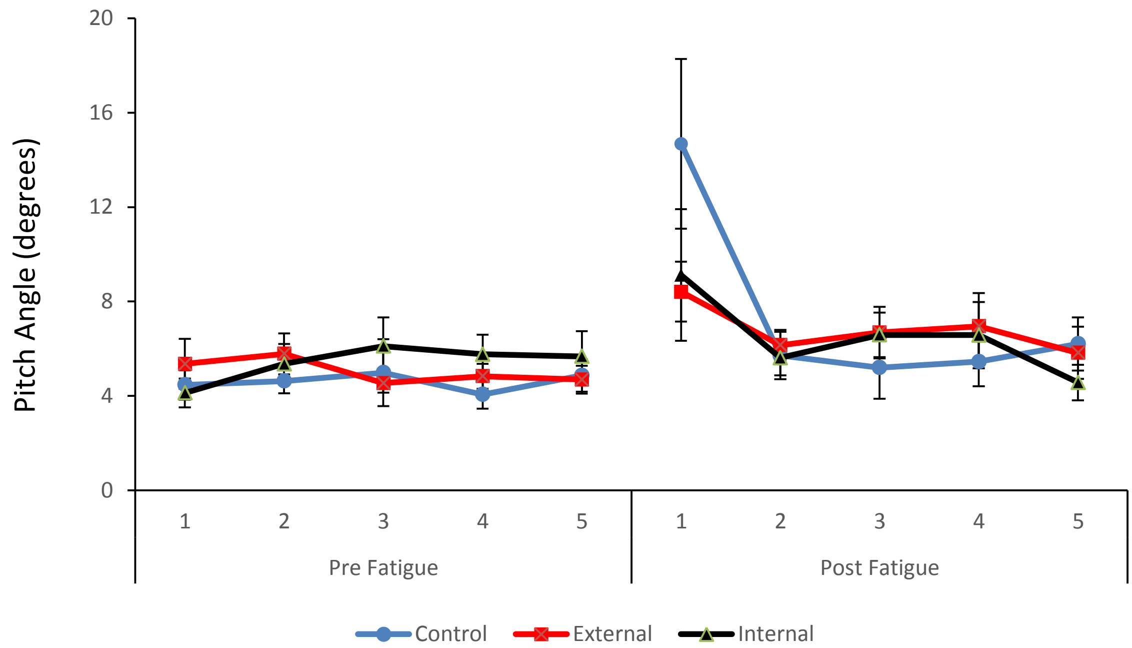

Figure 6. Mean Pitch Angle for Trials 1-5 for Pre-Fatigue and Post-Fatigue Conditions for each Attention Focus Group. Note that error bars reflect standard error of the mean values. Note that the three-way interaction between attention focus group, fatigue and trial was not statistically significant.

4.4.2 Pitch Velocity

Mauchley's test indicated that the assumption of sphericity had been violated for the main effect of trial ($\chi^2(9) = 40.748$, $p < 0.001$) and the interaction effect between fatigue and trial ($\chi^2 = 52.917$, $p < 0.001$) for pitch velocity. To address the violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity.

The results revealed statistically significant main effects for fatigue [$F(1, 41.237) = 19.124$, $p < 0.001$, $\eta_p^2 = 0.477$] and trial [$F(2.59, 41.237) = 5.222$, $p = 0.005$, $\eta_p^2 = 0.199$] for pitch velocity.

The results also showed a statistically significant interaction effect between fatigue and trial [$F(1.964, 41.237) = 4.208$, $p = 0.022$, $\eta_p^2 = 0.167$]. No other statistically significant main effects or two-way interaction effects were observed.

The results also did not reveal a statistically significant three-way interaction effect between attention focus group, fatigue and trial [$F(3.927, 41.237) = 1.906$, $p = 0.129$, $\eta_p^2 = 0.154$]. Similar to pitch angle, although not statistically significant, the decision was made to further explore the three-way interaction effect between attention focus group, fatigue, and trial for pitch velocity (Figure 7). Orthogonal polynomial testing for trial was conducted for pre-fatigue and post-fatigue conditions for each attention focus group. This follow-up analysis revealed a statistically significant trial effect for the post-fatigue condition for the control attention focus group [$F(4, 28) = 5.287$, $p = 0.003$, $\eta_p^2 = 0.430$]. The trend components observed for this trial effect were as follows: linear ($p = 0.058$, accounting for 54.9% of the variance), quadratic ($p = 0.052$, accounting for 35.4% of the variance), cubic ($p = 0.027$, accounting for 9.7% of the variance) and quartic ($p = 0.822$, accounting for 0.03% of the variance). No statistically significant trial effects were observed for the post-fatigue condition for the external or internal attention focus groups or for the pre-fatigue condition for external, internal, or control attention focus groups.

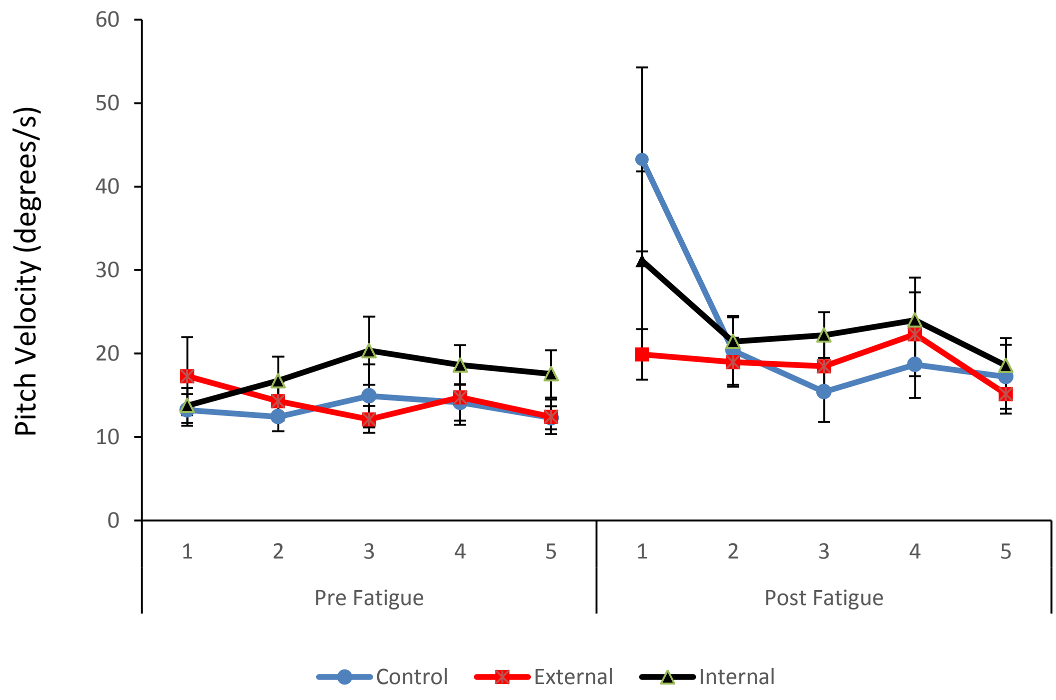

Figure 7. Mean Pitch Velocity for Trials 1-5 for Pre-Fatigue and Post-Fatigue Conditions for each Attention Focus Group. Note that error bars reflect standard error of the mean values. Note that the three-way interaction between attention focus group, fatigue and trial was not statistically significant.

4.4.3 Roll Angle

Mauchley's test indicated that the assumption of sphericity had been violated for the interaction effect between fatigue and trial ($\chi^2(9) = 17.31$, $p = 0.045$). To address this violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity.

The results revealed a statistically significant main effect of fatigue [$F(1,84) = 11.087$, $p = 0.003$, $\eta_p^2 = 0.346$]. There was also a statistically significant interaction effect between attention focus group and trial [$F(8, 84) = 2.259$, $p = 0.031$, $\eta_p^2 = 0.177$]. No other statistically significant main effects or two-way interaction effects were observed.

The three-way interaction between attention focus group, fatigue, and trial was also not statistically significant [$F(7.076, 74.299) = 1.641$, $p = 0.136$, $\eta_p^2 = 0.136$]. Similar to pitch angle and pitch velocity, although not statistically significant, the decision was made to further explore the three-way interaction effect between attention focus group, fatigue, and trial for roll angle (Figure 8). Orthogonal polynomial testing for trial was conducted for pre-fatigue and post-fatigue conditions for each attention focus group. This follow-up analysis revealed a statistically significant trial effect for the post-fatigue condition for the control attention focus group [$F(4, 28) = 3.374$, $p = 0.023$, $\eta_p^2 = 0.325$]. The trend components observed for this trial effect were as follows: linear ($p = 0.097$, accounting for 28.5% of the variance), quadratic ($p = 0.058$, accounting for 46.8% of the variance), cubic ($p = 0.214$, accounting for 16.8% of the variance) and quartic ($p = 0.194$, accounting for 7.9% of the variance). No statistically significant trial effects were observed for the post-fatigue condition for the external or internal attention focus groups or for the pre-fatigue condition for external, internal, or control attention focus groups.

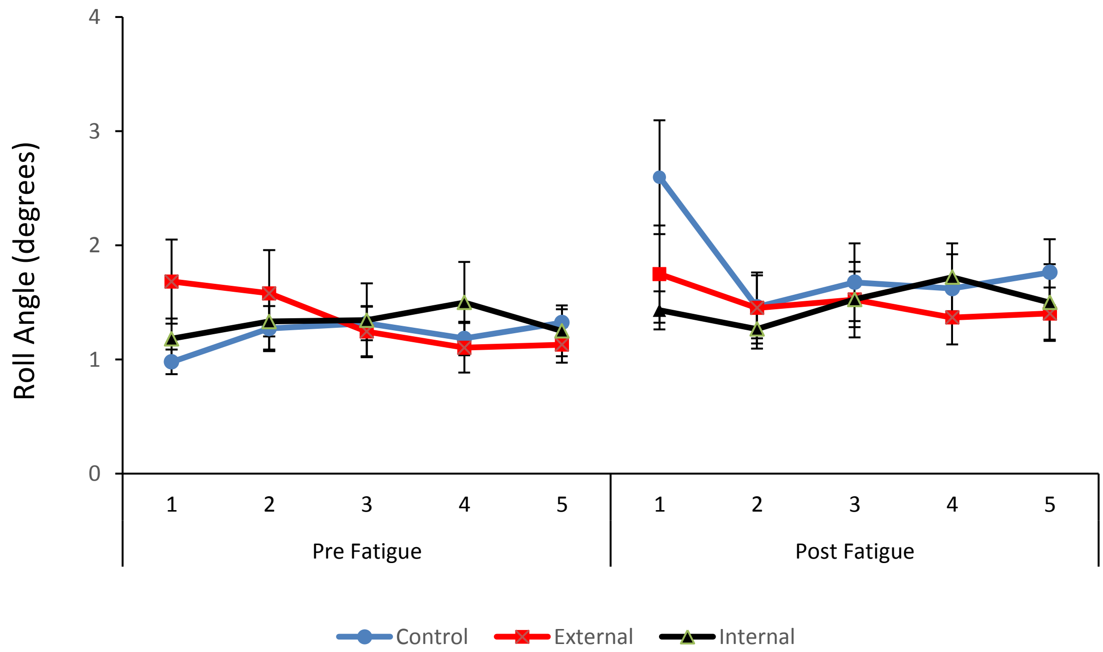

Figure 8. Mean Roll Angle for Trials 1-5 for Pre-Fatigue and Post-Fatigue Conditions for each Attention Focus Group. Note that error bars reflect standard error of the mean values. Note that the three-way interaction between attention focus group, fatigue and trial was not statistically significant.

4.4.4 Roll Velocity

Mauchley's test indicated that the assumption of sphericity had been violated for the interaction effect between fatigue and trial ($\chi^2(9) = 24.999$, $p = 0.003$). To address this violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity.

The results revealed a statistically significant main effect of fatigue [$F(1,84) = 15.195$, $p = 0.001$, $\eta_p^2 = 0.42$]. The results also showed statistically significant interaction effects between attention focus group and trial [$F(7.118, 62.661) = 2.590$, $p = 0.18$, $\eta_p^2 = 0.198$] and between fatigue and trial [$F(2.984, 62.661) = 3.107$, $p = 0.033$, $\eta_p^2 = 0.129$]. No other statistically significant main effects or two-way interaction effects were observed.

The three-way interaction effect between attention focus group, fatigue and trial was also not statistically significant [$F(5.958, 62.661) = 2.251$, $p = 0.050$, $\eta_p^2 = 0.177$]. Similar to pitch angle, pitch velocity, and roll angle, although not statistically significant, the decision was made to further explore the three-way interaction effect between attention focus group, fatigue, and trial for roll velocity (Figure 9). Orthogonal polynomial testing for trial was conducted for pre-fatigue and post-fatigue conditions for each attention focus group. This follow-up analysis revealed a statistically significant trial effect for the post-fatigue condition for the control attention focus group [$F (4, 28) = 3.301$, $p = 0.025$, $\eta_p^2 = 0.320$]. The trend components observed for this trial effect were as follows: linear ($p = 0.271$, accounting for 16.3% of the variance), quadratic ($p = 0.083$, accounting for 45.2% of the variance), cubic ($p = 0.143$, accounting for 14.6% of the variance) and quartic ($p = 0.018$, accounting for 24.0% of the variance). No statistically significant trial effects were observed for the post-fatigue condition for the external or internal attention focus groups or for the pre-fatigue condition for external, internal, or control attention focus groups.

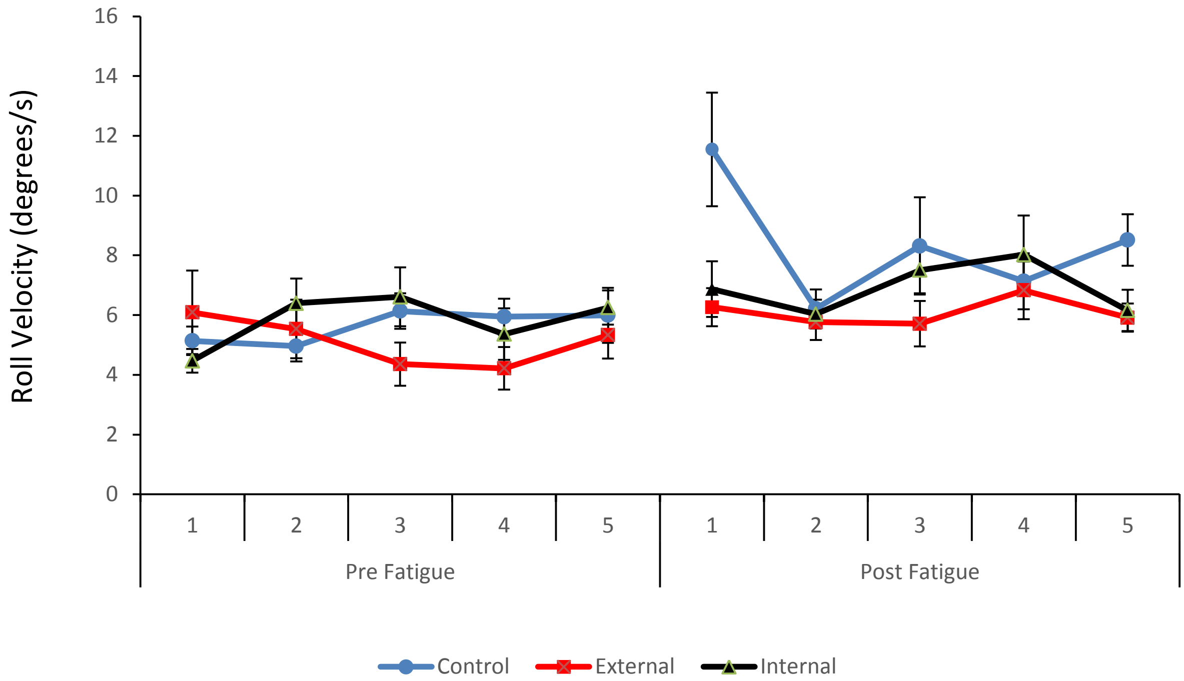

Figure 9: Mean Roll Angle for Trials 1-5 for Pre-Fatigue and Post-Fatigue Conditions for each Attention Focus Group. Note that error bars reflect standard error of the mean values. Note that the three-way interaction between attention focus group, fatigue and trial was not statistically significant.

4.5 Tilt-board

Table 7 presents the results of the 3 (attention focus group: control, external, internal) x 2 (fatigue: pre, post) x 5 (trial: 1-5) between and within-subjects ANOVA conducted for the amplitude variability of the tilt-board.

Table 7

Probability Levels for the Main Effects, Two-way Interaction Effects, and Three-way Interaction Effect for the ANOVAs Conducted for Amplitude Variability of the Tilt-board

Effects	Amplitude Variability of Tilt-board
Attention Focus Group	0.920
Fatigue	**0.039**
Trial	**0.017**
Attention Focus Group x Fatigue	0.180
Attention Focus Group x Trial	0.359
Fatigue x Trial	0.381
Attention Focus Group x Fatigue x Trial	0.092

4.5.1. Amplitude variability

The results revealed a statistically significant main effect for fatigue [F(1, 84) = 4.859, p = 0.039, η_p^2 = 0.188] and trial [F(4, 84) = 3.204, p = 0.017, η_p^2 = 0.132] for amplitude variability of the tilt-board. No other statistically significant main effects or two-way interaction effects were observed.

The results also did not reveal a statistically significant three-way interaction effect between attention focus group, fatigue, and trial for amplitude variability of the tilt-board [F(8, 84) = 1.781, p = 0.092, η_p^2 = 0.145]. Similar to the trunk sway measures, although not statistically significant, the decision was made to further explore the three-way interaction effect between attention focus group, fatigue, and trial for amplitude variability of the tilt-board (Figure 10). Orthogonal polynomial testing for trial was conducted for pre-fatigue and post-fatigue conditions for each attention focus group. This follow-up analysis revealed a statistically significant trial effect for the post-fatigue condition for the control attention focus group [$F(4, 28) = 3.641$, $p = 0.016$, $\eta_p^2 = 0.342$]. The trend components observed for this trial effect were as follows: linear ($p = 0.081$, accounting for 18.2% of the variance), quadratic ($p = 0.114$, accounting for 38.4% of the variance), cubic ($p = 0.036$, accounting for 43.3% of the variance) and quartic ($p = 0.879$, accounting for 0.12% of the variance). No statistically significant trial effects were observed for the post-fatigue condition for the external or internal attention focus groups or for the pre-fatigue condition for external, internal, or control attention focus groups.

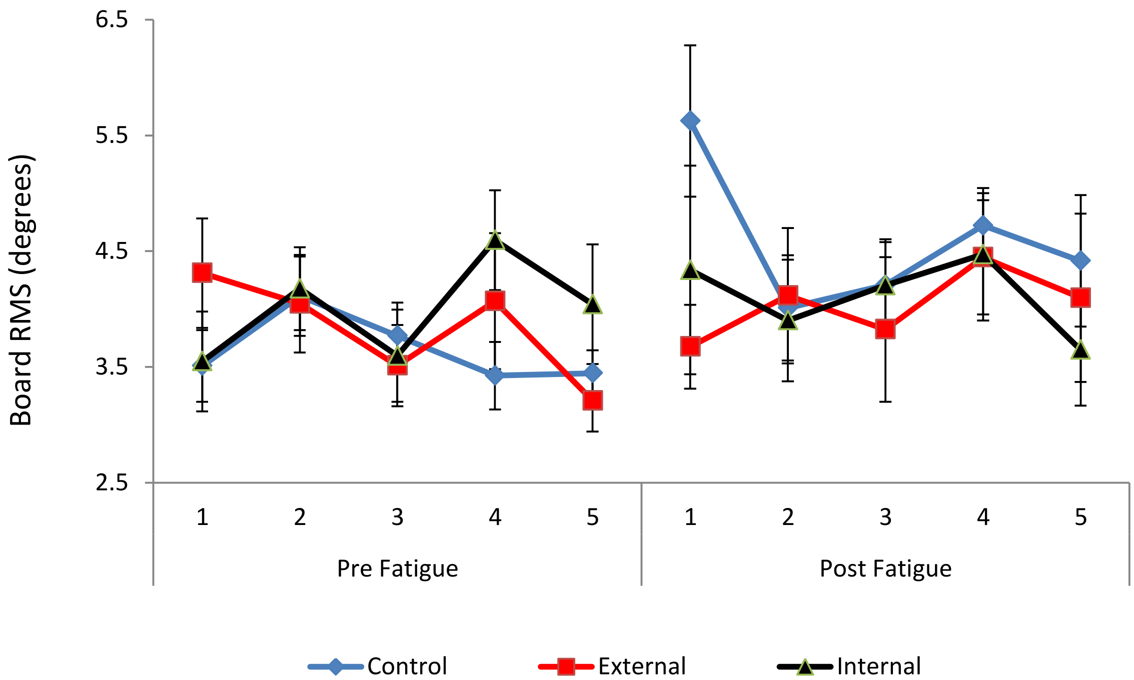

Figure 10. Mean Amplitude Variability of the Tilt-board for Trials 1-5 for Pre-Fatigue and Post-Fatigue Conditions for each Attention Focus Group. Note that error bars reflect standard error of the mean values. Note that the three-way interaction between attention focus group, fatigue and trial was not statistically significant.

4.6 Surface Electromyography

4.6.1 Mean Spike Amplitude

Table 8 presents the results of the 3 (attention focus group: control, external, internal) x 2 (fatigue: pre, post) x 5 (trial: 1-5) between and within-subjects ANOVAs that were conducted separately for the mean spike amplitude of the left and right TA and MG.

Table 8

Probability Levels for the Main Effects, Two-way Interaction Effects, and Three-way Interaction Effect for the ANOVAs Conducted for Mean Spike Amplitude for left and right TA and MG

Effects	LTA	RTA	LMG	RMG
Attention Focus Group	.600	.745	.246	.661
Fatigue	**.008**	.073	**.020**	**.018**
Trial	**.017**	**.001**	.413	.967
Attention Focus Group x Fatigue	.766	.422	.737	.687
Attention Focus Group x Trial	.182	.315	.914	.804
Fatigue x Trial	.488	.062	.209	.408
Attention Focus Group x Fatigue x Trial	.880	.720	.571	.437

4.6.2 Mean Spike Amplitude for Left and Right TA

The results revealed a statistically significant main effect for fatigue [$F(1, 84) = 8.461$, $p = 0.008$, $\eta_p^2 = 0.287$]. The mean spike amplitude was significantly larger in the post-fatigue compared to the pre-fatigue condition (Figure 11). The results also showed a statistically significant main effect for trial [$F(4, 84) = 3.217$, $p = 0.017$, $\eta_p^2 = 0.133$] for left TA mean spike amplitude. A significant (decreasing) linear trend component was observed for this effect ($p = 0.015$, accounting for 78.7% of the variance). There were no statistically significant two-way interaction effects observed. As well, the three-way interaction effect between attention focus group, fatigue, and trial was not statistically significant. As the significance of this interaction effect was $p = 0.880$, a decision was made not to further explore this interaction effect for left TA mean spike amplitude.

Mauchley's test indicated that the assumption of sphericity had been violated for the interaction effect of fatigue and trial ($\chi^2(9) = 24.890$, $p = 0.003$) for right TA mean spike amplitude. To address this violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity. The results showed a significant main effect of trial [$F(4, 84) = 5.565$, $p = 0.001$, $\eta_p^2 = 0.209$] for right TA mean spike amplitude . A significant (decreasing) linear trend component was observed for this effect ($p < 0.001$, accounting for 84.9% of the variance). Similar to LTA mean spike amplitude, there were no statistically significant two-way interaction effects observed. As well, the three-way interaction effect between attention focus group, fatigue, and trial was not statistically significant. As the significance of this interaction effect was $p=0.720$, a decision was made to not further explore this interaction effect.

4.6.3 Mean Spike Amplitude for Left and Right MG

Mauchley's test indicated that the assumption of sphericity had been violated for the main effect for trial ($\chi^2(9) = 25.668$, $p = 0.002$) for left MG mean spike amplitude. To address this violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity. The results revealed a significant main effect of fatigue [$F(1, 84) = 6.374$, $p = 0.020$, $\eta_p^2 = 0.233$] for left MG mean spike amplitude. The mean spike amplitude was significantly reduced in the post-fatigue compared to the pre-fatigue condition (Figure 11). There were no other statistically significant main effects or two-way interaction effects observed. As well, the three-way interaction effect between attention focus group, fatigue, and trial was not statistically significant. As the significance of this interaction effect was $p = 0.571$, a decision was made to not further explore this interaction effect.

Mauchley's test indicated that the assumption of sphericity had been violated for the main effect of trial ($\chi^2(9) = 20.637$, $p = 0.015$) and for the interaction effect between fatigue and trial ($\chi^2(9) = 16.936$, $p = 0.050$) for right MG mean spike amplitude. To address this violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity. The results revealed a significant main effect of fatigue [$F(1, 84) = 6.567$, $p = 0.018$, $\eta_p^2 = 0.238$]. The mean spike amplitude was significantly reduced in the post-fatigue compared to the pre-fatigue condition (Figure 11). Similar to LMG mean spike amplitude, there were no other statistically significant main effects or two-way interaction effects observed. As well, the three-way interaction between attention focus group, fatigue, and trial was not significant. As the significance of this interaction effect was $p = 0.437$, a decision was made to not further explore this interaction effect.

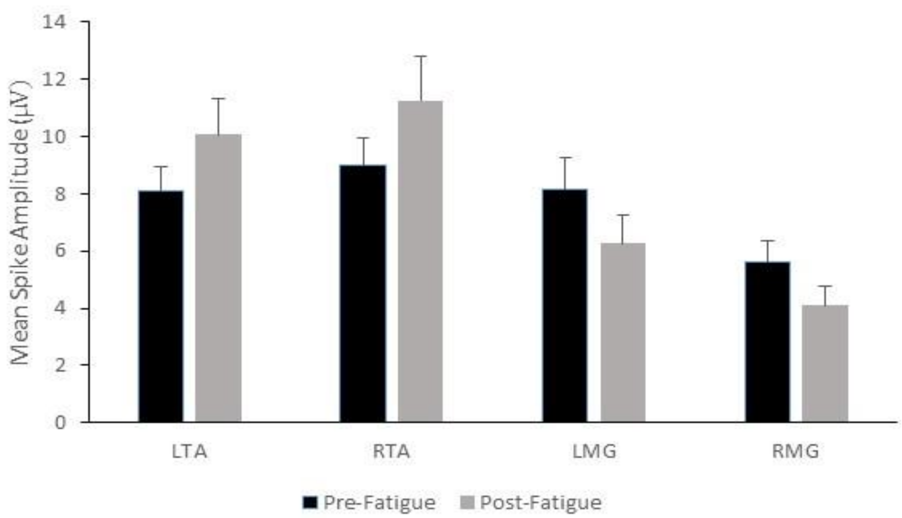

Figure 11. Mean Pre-Fatigue and Post-Fatigue Mean Spike Amplitude (MSA) for the left and right TA and MG. Note that error bars reflect standard error of the mean values. Mean spike amplitude significantly increased post-fatigue for the left and right TA, while MSA significantly decreased post-fatigue for the left and right MG.

4.6.4 Total Number of Spikes

Table 9 presents the results of the 3 (attention focus group: control, external, internal) x 2 (fatigue: pre, post) x 5 (trial: 1-5) between and within-subjects ANOVAs that were conducted separately for the total number of spikes for the left and right TA and MG.

Table 9

Probability Levels for the Main Effects, Two-way Interaction Effects, and Three-way Interaction Effect for the ANOVAs Conducted for the Total Number of Spikes for left and right TA and MG

Effects	LTA	RTA	LMG	RMG
Attention Focus Group	.549	.829	.660	.842
Fatigue	.124	**.044**	**.004**	**.012**
Trial	**<.001**	**.001**	.136	.518
Attention Focus Group x Fatigue	.283	.735	.361	.954
Attention Focus Group x Trial	.494	.922	.610	.099
Fatigue x Trial	.127	**.002**	.051	.097
Attention Focus Group x Fatigue x Trial	.463	.704	.216	.117

4.6.5 Total Number of Spikes for Left and Right TA

Mauchley's test indicated that the assumption of sphericity had been violated for the interaction effect between fatigue and trial interaction ($\chi^2(9) = 20.300$, $p = 0.017$) for left TA total number of spikes. To address this violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity. The results revealed a significant main effect of trial [$F(4, 84) = 8.193$, $p < 0.001$, $\eta_p^2 = 0.281$] for left TA total number of spikes. A significant decreasing linear trend component was observed for this effect ($p < 0.001$, accounting for 74.0% of the variance). There were no other statistically significant main effects or two-way interaction effects observed. As well, the three-way interaction between attention focus group, fatigue, and trial was not statistically significant. As the significance of this interaction effect was $p = 0.463$, a decision was made to not further explore this interaction effect.

Mauchley's test indicated that the assumption of sphericity had been violated for the main effect of trial ($\chi^2(9) = 18.033$, $p < 0.035$) for right TA total number of spikes. To address this violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity. The results revealed a significant main effect of fatigue [$F(1, 84) = 4.602$, $p = 0.004$, $\eta_p^2 = 0.180$] and trial [$F(3.863, 84) = 5.231$, $p = 0.001$, $\eta_p^2 = 0.199$]. There was also a significant interaction effect between fatigue-by-trial [$F(4, 84) = 4.553$, $p = 0.002$, $\eta_p^2 = 0.178$]. A significant decreasing linear trend component was observed for trial in the pre-fatigue condition ($p < 0.001$, accounting for 54.8% of the variance) while a significant cubic trend component was observed for trial in the post-fatigue condition ($p = 0.004$, accounting for 83.0% of the variance). There were no other statistically significant main effects or two-way interaction effects observed. As well, the three-way interaction effect between attention focus group, fatigue, and trial was not statistically significant. As the significance of this interaction effect was $p = 0.704$, a decision was made to not further explore this interaction effect.

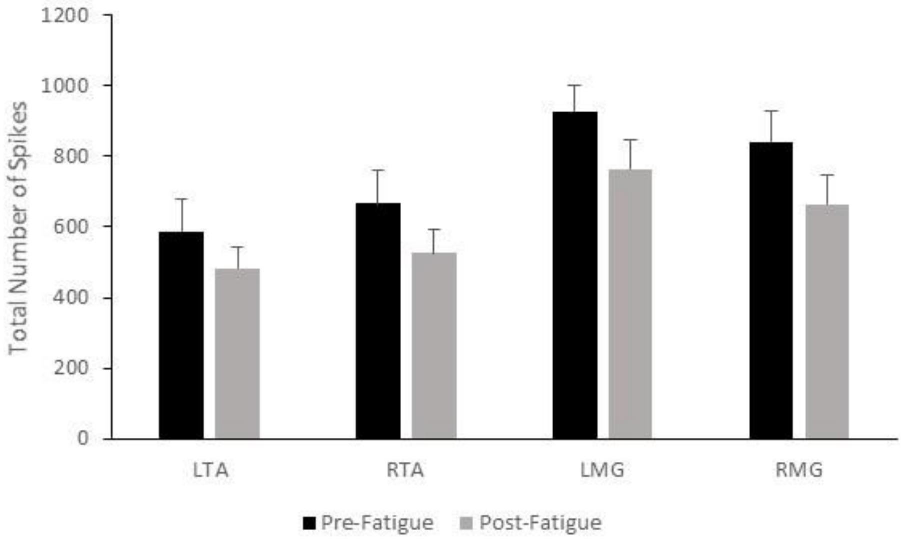

Figure 12: Mean Total Number of Spikes for Pre-Fatigue and Post-Fatigue Conditions for the left and right TA and MG. Note that error bars reflect standard error of the mean values.

4.6.6 Total Number of Spikes for Left and Right MG

Mauchley's test indicated that the assumption of sphericity had been violated for the interaction between fatigue-by-trial ($\chi^2(9) = 16.936$, $p = 0.050$) for left MG total number of spikes. To address this violation of the assumption of sphericity, degrees of freedom were corrected using the Huynh-Feldt estimate of sphericity. The results revealed a statistically significant main effect for fatigue [$F(1, 84) = 10.624$, $p = 0.004$, $\eta_p^2 = 0.331$] for left MG total number of spikes. The left MG total number of spikes was significantly reduced in the post-fatigue compared to the pre-fatigue condition (Figure 12). There were no other statistically significant main effects or two-way interaction effects observed.

The three-way interaction effect between attention focus group, fatigue, and trial was not statistically significant [$F(7.526,79.024) = 1.394$, $p = 0.216$, $\eta_p^2 = 0.117$] for left MG total number of spikes. Similar to the trunk sway and tilt-board measures, although not statistically significant, the decision was made to further explore the three-way interaction effect between attention focus group, fatigue, and trial for left MG total number of spikes (Figure 13). Orthogonal polynomial testing for trial was conducted for pre-fatigue and post-fatigue conditions for each attention focus group. This follow-up analysis revealed a statistically significant trial effect for the post-fatigue condition for the control attention focus group [$F(4, 28) = 2.707$, $p = 0.050$, $\eta_p^2 = 0.279$]. The trend components observed for this trial effect were as follows: linear ($p = 0.081$, accounting for 70.8% of the variance), quadratic ($p = 0.352$, accounting for 8.4% of the variance), cubic ($p = 0.219$, accounting for 16.1% of the variance) and quartic ($p = 0.214$, accounting for 4.7% of the variance). No statistically significant trial effects were observed for the post-fatigue condition for the external or internal attention focus groups or for the pre-fatigue condition for external, internal, or control attention focus groups.

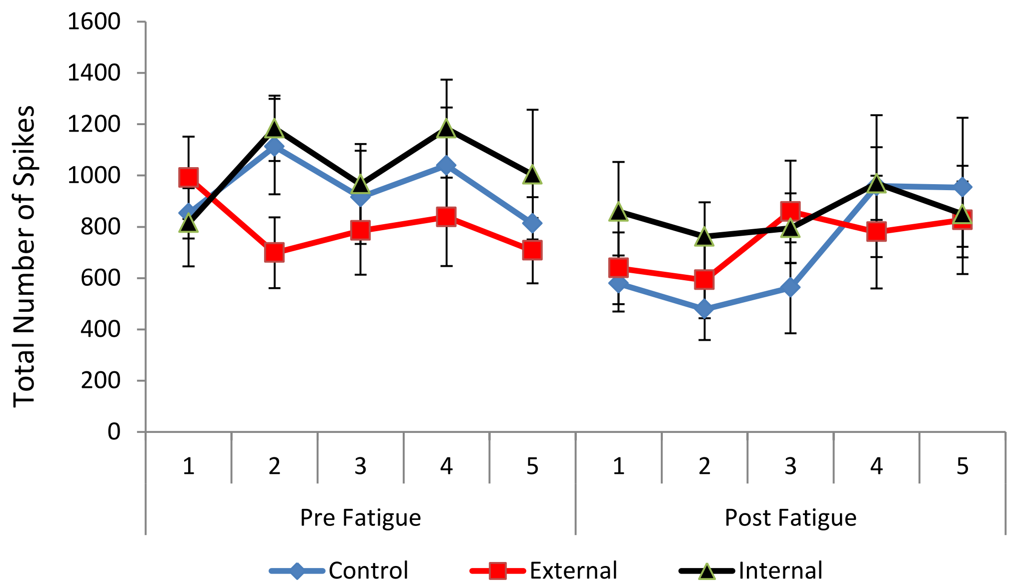

Figure 13. Mean Total Number of Spikes for the left MG for trials 1-5 for Pre-Fatigue and Post-Fatigue Conditions for each Attention Focus Group. Note that error bars reflect standard error of the mean values. Note that the three-way interaction between attention focus group, fatigue and trial was not statistically significant.

The results revealed a statistically significant main effect of fatigue [F (1, 84) = 7.574, p = 0.012, η_p^2 = 0.265] for right MG total number of spikes. The right MG total number of spikes was significantly reduced in the post-fatigue compared to the pre-fatigue condition (Figure 12). There were no other statistically significant main effects or two-way interaction effects observed. As well, the three-way interaction between attention focus group, fatigue, and trial was not statistically significant [F(8,84) = 1.481, p =0.177, η_p^2 = 0.124]. As the significance of this interaction effect was p=0.xx, a decision was made to further explore this interaction effect.

The three-way interaction effect between attention focus group, fatigue, and trial was not statistically significant [F(8,84) = 1.481, p = 0.177, η_p^2 = .005]. Although not statistically significant, the decision was made to further explore the three-way interaction effect between attention focus group, fatigue, and trial for right MG total number of spikes (Figure 14). Orthogonal polynomial testing for trial was conducted for pre-fatigue and post-fatigue conditions for each attention focus group. No statistically significant trial effects were observed for the pre-fatigue or post-fatigue condition for external, internal, or control attention focus groups.

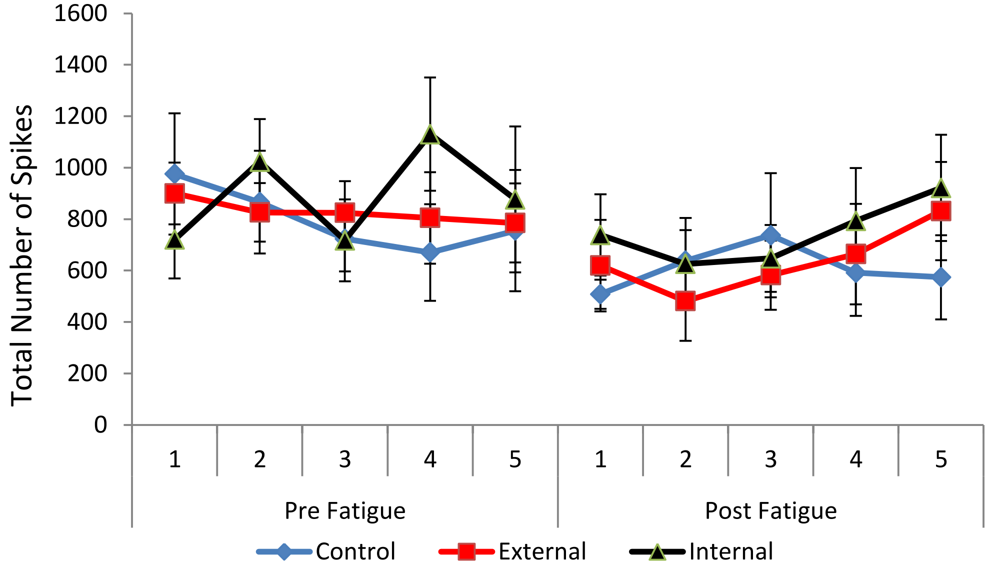

Figure 14. Mean Total Number of Spikes for the right MG for Trials 1-5 for Pre-Fatigue and Post-Fatigue Conditions for each Attention Focus Group. Note that error bars reflect standard error of the mean values. Note that the three-way interaction between attention focus group, fatigue and trial was not statistically significant.

CHAPTER 5: DISCUSSION

The purpose of this thesis was to determine if attention focus instructions could modify the effects of fatigue on balance control. To examine this possibility, participants, assigned to one of three different attention focus groups, were required to maintain their balance on an unstable support surface (i.e., tilt-board) in a pre-fatigue and post-fatigue condition. All participants performed five balance trials in the pre-fatigue condition and received the same common instruction concerning the task objective. Then, all participants experienced the fatigue protocol during which the ankle plantar-flexors were fatigued by performing heel raises. Following the fatigue protocol, participants received the attention focus instruction specific to the group to which they were assigned (i.e., external, internal, control) and performed five balance trials in the post-fatigue condition.

First, it was hypothesized that fatigue of the ankle plantar-flexors would negatively influence balance control as shown through greater postural instability and altered magnitude (i.e., increased) and frequency (i.e., decreased) of lower limb muscle activity. Second, it was also hypothesized that the effects of fatigue on balance control especially in the trials immediately following the fatigue protocol would be attenuated in individuals provided with an instructional set that encouraged the adoption of an external attention focus compared to individuals who received an instructional set that led to the adoption of an internal attention focus or individuals who received no specific attention focus instructions. Thus, from the between subjects (attention focus group) and within subjects (fatigue condition, trial) experimental design, it was expected that a three-way interaction effect between attention focus group, fatigue, and trial would be observed.

The results of the thesis show strong support for the first hypothesis and partial support for the second hypothesis. Overall, the results demonstrated that the fatigue protocol was successful in eliciting changes in balance. These changes were reflective of greater postural instability as evidenced by increased trunk pitch and roll sway and larger amplitude variability of the tilt-board. The effect of fatigue on the magnitude and frequency of lower limb muscle activity was less consistent. There was an increased magnitude and decreased frequency of TA muscle activity and a decreased magnitude and decreased frequency of MG muscle activity. When fatigued, instructions whether externally-based or internally-based appeared to mitigate the effect of fatigue on balance outcomes (i.e., less trunk pitch and roll sway and less amplitude variability of the tilt-board). External or internal instructions did not appear to alter magnitude and frequency of lower limb muscle activity.

6.1. Fatigue Effects on Balance Control

The purpose of this thesis was to examine the effects of attention focus instructions on minimizing the effects of fatigue on balance control. Thus, a requirement for this thesis was to successfully elicit fatigue in the participants. The decision was made to isolate fatigue to the ankle plantar-flexors using a heel raise task and have participants balance on an unstable support surface before and after this fatiguing protocol. The expectation was that the localized muscular fatigue of the ankle plantar-flexors would contribute to changes in balance control. The fatigue protocol used in the present thesis has been previously shown to generate changes in balance control during two-footed stance tasks (Corbeil et al. 2003) and single-leg stance tasks (Aldterton et al. 2003). An examination of the main effect for fatigue, the two-way interaction between fatigue and trial, and the three-way interaction between attention focus group, fatigue and trial (targeting the performance of the control group in the fatigued condition) for the trunk sway, tilt-board, and lower limb muscle activity measures can provide insight into whether or not the fatiguing protocol resulted in fatigue effects on balance.

The results of the thesis show that the fatigue protocol was successful in eliciting changes in the measures used to infer balance performance on the task. For example, if attention focus group or trial is not considered, 11 of the 13 measures that were examined demonstrated a statistically significant fatigue main effect (with another measure showing a trend to significance, $p = 0.073$). In addition, four of the 13 measures that were examined demonstrated a fatigue by trial interaction effect (with another four measures showing a trend to significance, $p = 0.051$ to $p = 0.097$). It was observed that these interaction effects were primarily driven by poorer performance during the first trial in the fatigued condition. Additionally, when considering attention focus group, the control group who received no specific instructions demonstrated a stronger fatigue effect especially in the first trial immediately after the fatiguing protocol relative to the external or internal attention focus groups. These effects for the control group were observed primarily in the trunk sway and tilt-board measures. The findings observed for this particular group of individuals were expected and support previous work examining the effects of different fatigue protocols on balance performance (i.e., consistent observations of poorer performance, see Table 2 and Table 3). Furthermore, the first trial finding is in line with research reporting that the duration of the fatigue effect may be quite brief and can depend on the nature of the fatiguing protocol (Paillard 2012) and that to evaluate fatigue effects over multiple trials the fatiguing exercise might need to be repeated (Paillard 2012, Corbeil et al. 2003, Bisson et al 2010, Vuillerme, Forestior & Norgier 2002).

Thus, these results show that the fatigue protocol used in conjunction with balancing on an unstable support surface generated fatigue-related changes in balance control with these effects appearing most prominent in the trial immediately post fatigue. Poorer performance in the fatigue condition was observed as evidenced by increased trunk pitch and roll sway, increased amplitude variability of the tilt-board, and increased magnitude and decreased frequency of TA muscle activity and a decreased magnitude and decreased frequency of MG muscle activity. The decreases observed in total number of spikes are characteristic of the EMG frequency fatigue relationship (Loscher, Cresswell, & Thortensson 1994) and indicate that both muscles may have been fatigued.

The inverse relationship between the TA and MG seen in mean spike amplitude may be indicative of the expected differing levels of fatigue between muscles due to the nature of the fatigue protocol. The increases in amplitude in the TA are consistent with results seen in repeated submaximal contractions (Krogh-Lund & Jorgensen 1993) which would be necessary given the nature of the balance task, requiring constant adjustments of the ankle musculature. In an attempt to further quantify the magnitude of adjustments necessary in order to complete the balance task, the maximal voluntary isometric contraction of each muscle was recorded for three participants. The peak to peak amplitude during the MVC of each muscle was compared to the average peak to peak amplitude of each muscle across all balance trials. In these individuals during the course of the balance trials they averaged a peak to peak amplitude of 45% and 40% MVC for the medial gastrocnemius and tibialis anterior respectively. The decreases in mean spike amplitude observed in the MG may be a result of this muscle being the primary target of the fatigue protocol. MG mean spike amplitude likely would have increased over the course of the fatigue protocol, until it reached a point at which near maximal effort was required to continue with the fatigue protocol. If this was the case amplitude of the signal would be expected to decrease for subsequent contractions (Bigland-Ritchie, Jones, & Woods 1979) and may explain the decreased MG mean spike amplitude observed in the post-fatigue trials. An alternative explanation for the inverse relationship is that the position of the individual on the tilt-board was shifted when in a fatigued state to allow for the TA to contribute more than the MG to maintaining balance on the tilt-board.

In addition, as the experimental design examined differences between three attention focus groups, it was important to also quantitatively assess the effects of the fatigue protocol across the three groups and ensure there were no differences between groups that could be accounted for by differences in perceived exertion and the time spent in the fatigue protocol. No attention focus group differences were observed for the Borg rating of perceived exertion and the time to fatigue measures. There was a trend for the external group to have higher perceived exertion scores and longer times to fatigue. Although these measures were collected as a means to ensure no differences existed between groups in the nature of the fatigue protocol, it is possible due to the subjective nature of the perceived rating scale and the ability to voluntarily end the fatiguing exercise that the fatiguing protocol was not consistent between groups.

6.2. Effects of Attention Focus Instructions on Reducing Fatigue Effects on Balance Control

One of the hypotheses related to this thesis was that attention focus instructions would reduce the effects of fatigue on balance control. Thus, an examination of the three-way interaction effect between attention focus group, fatigue and trial was important. Although, no statistically significant three-way interaction effect was observed, the decision was made to further explore this relationship due to the stated purpose of this thesis. Furthermore, there was some evidence from the two-way interactions that this effect may be relevant to examine and did not reach significance possibly due to the underpowered nature of the experimental design.

The three-way interactions for all four trunk sway measures, the tilt-board measure, and two of the eight EMG measures were explored. The dominant finding was of a difference in the control group in the post-fatigue condition for the trunk sway and tilt-board measures. The trends across trial observed for the control attention focus group were predominantly quadratic in nature with linear and cubic components as well, decreasing after the first trial post-fatigue. The internal and external attention focus groups did not show any significant trends across trials in the post-fatigue condition. Furthermore, no significant trends across trial were observed in the pre-fatigue condition for any attention focus group suggesting that the trend across trial was similar between groups in this state. Thus, only in the post-fatigue condition was there a difference in the trends observed across trial with the effect of fatigue observed in the initial trial in the post-fatigued condition for the control group.

The lack of a trend across trials for the external and internal attention focus groups in the post-fatigue condition compared to the control group is suggestive that both of these instructional sets were successful in minimizing the effects of fatigue on balance control most specifically in the first trial post fatigue. If an effect was not exerted by the instructions, then all three attention focus groups should have demonstrated this same trend. The aforementioned trend was evident across all trunk sway measures and the amplitude variability of the tilt-board.

Minimizing the effect of fatigue on balance control was expected for the external attention focus group. A number of studies have shown that external attention focus instructional sets relative to internal or no specific attention focus instructions sets benefit performance and learning of many different skills and tasks, including balance-type tasks (Wulf 2007). Interestingly, in these studies, the benefit of external attention focus instructions is generally observed over a longer period of practice (Lohse 2014), or in retention (McNevin et al. 2003) and transfer type tests (Totsika & Wulf 2003). Thus, the results from this thesis provide support for an immediate effect of instruction on performance as the effect was observed on the first trial after receiving the external attention focus instructional set. An argument could be made that individuals in the external attention focus group were using this type of attention focus during the familiarization trials and pre-fatigue condition and thus it was not the first trial that participants attempted to use these instructions to maintain balance. There is some evidence that individuals typically prefer to use an external focus compared to an internal focus when provided with a choice between the two (Wulf, Shea, & Park 2001, Marchant, Clough, Crawshaw, & Levy 2009). Thus, if participants had previous exposure to external instructions for a similar task they may have intuitively adopted that focus. However, the fact that the internal attention focus instructions had the same beneficial effect seems to contradict this viewpoint. Although not expected the internal attention focus group also showed a reduced effect of fatigue on balance-related measures. Thus, if external is the predominant attention focus adopted during this type of task during the familiarization and pre-fatigue condition, performance in the internal group when there is a switch to a different type of focus should not show immediate effects as time would be needed to adjust to the “new” instructional set (Weiss, Reber & Owen 2008). Furthermore, if participants were indeed initially adopting an external focus it would be expected that the control group would have performed similarly to the external attention focus group. As such it is reasonable to assume this was not the case. Again, research has shown that individuals do have certain attention focus preferences (Marchant et al. 2009) and this remains a potential confound to explaining the results when comparing across groups with different individuals and not employing a full repeated design where participants performance would be compared across attention focus conditions.

Of note, although not significant there was a trend for the external attention focus group to have longer times to fatigue than the control and internal attention focus groups. If this is the case, the benefit of external attention focus could be even greater as it would be expected that those taking longer to fatigue may actually demonstrate a larger fatigue effect on balance (Pline, Madigan, & Nussbaum 2006) and thus external instructions minimize this effect even more so than the internal instructions or no instructions as all. Thus, even though external and internal show the same benefit it could be that external is better due to this potential confound.

Interestingly, an internal attentional focus instruction set also benefited performance in the post-fatigue condition to the same level as that observed for the external attentional focus instructions. This runs counter to the constrained action hypothesis and the vast amount of literature that has shown superior results (performance, retention, transfer tests) when adopting an external focus compared to an internal focus (Table 1). Furthermore, the difference in performance between the internal and to control groups is contrary to the suggestion that individuals may naturally adopt an external focus (source). With is in mind, it would appear that the constrained action hypothesis cannot be used to explain the observed effects and as such alternative explanations must be explored.

Important to note, is that during a pilot study where the same experimental procedure was examined, save for the replacement of the fatigue protol with 10 minutes of seated rest, no main effects of attention focus instructions were observed. This when combined with the results reported herein suggests that the presence of fatigue may be the contributing factor to the effects of either attention focus instruction set. With this in mind a possible explanation is that during high intensity exercise attention has been found to predominantly shift to physiological sensations associated with fatigue (Hutchinson & Tenenbaum 2007). As this would be expected to occur following the fatigue protocol, it is possible that the provision of either attention focus instruction set immediately following the fatigue protocol served to distract participants from these sensations and allowed for superior performance compared to the control group. Further work should examine whether different types of internal attention focus instructional sets (i.e. focus on trunk movements) have similar or different benefits to reducing the effects of fatigue on balance control. Alternatively, for individuals with no specific attention focus instructions, larger trunk sway and tilt-board movements which were observed may result from a shift in strategy to the trunk/hip to avoid the fatiguing effects at the ankle joint. These strategies in the control group may need time to provide benefit to performance or possibly after fatigue effects start to fade, a shift back to an ankle strategy may occur reducing trunk sway.

6.3. Limitations

It is acknowledged that this thesis is not without limitations. First and foremost the results of this thesis are only generalizable to healthy young adults as different results may have been observed for older adults or individuals with neurological or musculoskeletal deficits. Likewise the results contained herein are only generalizable to the specific fatigue protocol used to elicit localized muscular fatigue of the ankle plantar-flexors (i.e., heel raises). A lack of standardization of fatigue protocols has been acknowledged (Paillard 2012) as a limiting factor in comparing between different studies examining the effects of localized fatigue on balance. Furthermore as the results observed may be dependent on constraints imposed specific to the balance task examined (balancing with vision during two-footed stance on a board that tilts in the forward-backward direction), the results are only generalizable to the type of balance task explored in this thesis. As the effects of attention focus instructions rely on subtle differences in instructional sets, the results are only generalizable to the instructions used for this thesis. The results may not apply to the provision and use of different attention focus instructional sets.

Several assumptions were also made during the process of this thesis that may also serve as limitations. It was assumed that participants would adhere to the attention focus instructions provided and understand how to use the instructions to benefit balance performance. The results may have been influenced by individuals not adhering to the attention focus instructional sets. An attempt was made to account for this by asking for self-reported levels of instructional use however it was not possible to definitively ascertain these values. An additional assumption that was made was that maximal effort was put forth by participants during the fatigue protocol. Additionally the fatigue protocol was terminated when participants reported they no longer could or were unable to continue. As such the assumption was made that the participants were actually fatigued and if they were, it was to the same level within the three different attention focus groups.

It was assumed that the 12 familiarization trials provided to the participants prior to the experimental conditions were sufficient to provide a stable level of balance performance on the task. It is possible that the provision of additional familiarization trials was required to achieve this baseline performance and that interaction between fatigue and instruction effects may be more pronounced at that time.

Another limitation is that while foot placement was controlled to ensure consistency across trials for each participant, it was not controlled for across participants. It is possible that differences in foot placement may have differentially affected the dominance of the ankle musculature required to complete the balance task which may have affected both balance strategy used by participants as well as the muscular activity required to carry out a given balance control strategy

The results observed are limited to the balance related measures that were collected (trunk pitch and roll sway, amplitude variability of the tilt-board, and EMG of the lower leg muscles, TA and MG). Other balance measures that could have be examined (i.e., whole-body COM, joint angles, upper leg and trunk EMG) may have resulted in different effects of instruction in reducing fatigue effects on balance and provide additional insight into the strategy used to maintain balance under conditions of a fatigued state and instructional sets.

6.4 Future Directions

Future studies examining the use of attention focus instructions on balance control in the presence of muscular fatigue should incorporate full body kinematic analysis in order to quantify any changes in balance control strategy (i.e., ankle vs. hip strategy) as a result of attention focus instructions.

A future consideration to be studied is the effects of attention focus instructions at differing levels of fatigue as it is possible that a linear relationship may exist between the level of fatigue and effectiveness of instructions. Conversely there may exist, either a minimum fatigue threshold below which instructions will not be effective or a maximum threshold above which the effects of instructions cease.

Another future direction to be explored is the effects of attention focus on performance of other motor skills in the presence of fatigue. As the benefits of attention focus have previously established for numerous motor skills in non-fatigued states it is important to examine if the effectiveness of attention focus instructions during the presence of fatigue is task dependent (i.e., may benefit fatigued individuals while shooting a basketball, but not while making a golf putt).

As individuals with various neurological conditions and current musculoskeletal injuries are already at an increased risk of falling and risk of subsequent injury due to poorer balance control as a result of decreased muscular strength (Wolfson et al.1995), reduced joint specific range of motion (Hoch, Staton, & McKeon 2011) and possibly reduced proprioception (Relph, Herrington, & Tyson 2014), the benefits of using attention focus instructions to avoid fatigue is of particular importance in rehabilitative settings. As such efforts should be made to reduce the effects of fatigue on balance to prevent further risk of injury. That the use of attention focus instructions displays an immediate effect on counteracting the effect of fatigue on balance makes instructions even more valuable. By providing individuals during rehabilitation with attention focus instructions to use in the presence of fatigue to counter-act the effects, the potential for further injury may be lessened. These benefits are not limited to rehabilitative settings. The ability to avoid decreased balance control and potential falls is immensely valuable for individuals working at height, or with heavy machinery when the maintenance of balance is of the upmost importance, as the risk of falling and consequences related to falling may be increased in these situations.

6.5 Conclusions

This present thesis found that providing individuals with task relevant attention focus instructions has the potential to reduce the effects of localized muscular fatigue on balance performance. This was demonstrated by a trend towards lower trunk sway when provided with internal or external attention focus instructions immediately following exposure to a fatigue protocol. Further research is required to determine the effects of attention focus at different levels of fatigue and if it benefits individuals experiencing localized muscular fatigue while performing other motor skills, in order to ascertain the viability of using these types of instructions in everyday life.

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Appendix A

Brock University
Research Ethics Office
Tel: 905-688-5550 ext. 3035
Email: reb@brocku.ca
Bioscience Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE:	3/6/2013		
PRINCIPAL INVESTIGATOR:	ADKIN, Allan - Kinesiology		
FILE:	12-177 - ADKIN		
TYPE:	Masters Thesis/Project	STUDENT:	Richard Huff
		SUPERVISOR:	Allan Adkin

TITLE: Can attention focus minimize the effect of fatigue on postural control

ETHICS CLEARANCE GRANTED

Type of Clearance: NEW Expiry Date: 3/6/2013

The Brock University Bioscience Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement. Clearance granted from 3/6/2013 to 3/6/2013.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before 3/6/2013. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at http://www.brocku.ca/research/policies-and-forms/research-forms.

In addition, throughout your research, you must report promptly to the REB:

a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
c) New information that may adversely affect the safety of the participants or the conduct of the study;
d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved:

Brian Roy, Chair
Bioscience Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.

Appendix B

The ratings of perceived exertion (RPE) takes into account all that you are perceiving in terms of fatigue, including psychological, musculoskeletal, and environmental factors. This level of perceived physical effort is assigned a rating from the scale below:

RPE	
6	
7	very, very light
8	
9	very light
10	
11	fairly light
12	
13	somewhat hard
14	
15	hard
16	
17	very hard
18	
19	very, very hard
20	

On this scale, an RPE of 12 to 13 corresponds to approximately 60 to 79 percent of maximal heart rate. An RPE of 16 would correspond to about 90 percent of maximal heart rate. Thus, as a rule, most persons would exercise between 12 and 16 on this scale.

Appendix C

Health Questionnaire

1) Sex: Male Female

2) What is your date of birth? Year:________ Month:_________ Day:_________

3) Have you have been diagnosed with or are currently affected by any musculoskeletal, neurological or sensory that could interfere with your ability to complete the fatigue protocol or balance abilities?

Appendix D

Exit Questions (1a)

Participant ID:__________

1) On a scale form 0-100%, with 0 being not at all and 100 being at all times, how much did you use the given instructions during the balance task?

2) If you did not answer 100%, where/what else did you focus on during the task?

3) Was what you were told to focus on any different from what you were focusing on when you first learned the task?

Exit Questions (1b)

Participant ID:____________

1) What did you pay attention to or focus on when performing the balance task (this can be related to the task or not)?

2) Did this change over the course of the study?