THE RELATIONSHIP BETWEEN SINGLE LEG STANDING BALANCE AND THRESHOLD TO PASSIVE MOVEMENT DETECTION AT THE ANKLE JOINT

by

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Abstract

The control of human standing balance is established through the integration of vestibular, visual and somatosensory input within the central nervous system (Horak & MacPherson, 1996). Proprioception, together with other sensory feedback systems (i.e., vestibular and visual), contribute to body awareness and equilibrium (Gauchard et al., 2001; Hegeman, 2005; Westlake, 2007). However, there are mixed views as to the exact role that proprioception might play in controlling standing balance, with some researchers arguing that balance training can cause improvements in proprioception (Ribot et al., 1986; Clark et al.,1993; Ashton-Miller et al., 2001; Verhagen et al., 2004). Thirty healthy participants were exposed to thirty threshold to passive movement (TPM) trials (15 inversion and 15 eversion), and six single leg standing trials. Threshold to Passive Movement TPM responses were measured at 0.25 degrees/second in the inversion and eversion direction in thirty participants. Pre and Post to the TPM measures, participants underwent three single leg standing trials on a force plate, with the aim of investigating the relationship between single leg standing balance and ankle proprioception in the inversion and eversion directions. The methodologies chosen for this experiment resulted in a failure to reject the null hypothesis, thus requiring further investigations to begin to fully understand the relationship between proprioception and standing balance.

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1. Introduction

1.1 Background

Balance is essential in executing everyday skills from standing, to walking, running, or kicking a soccer ball. Balance is a term used for postural control; meaning the stabilization of posture, the support of voluntary movements, and the stabilization of head and limb orientation in relation to the body. The maintenance of postural control or balance requires that the body's centre of mass (CoM) remains within the limits of the supporting surface. The maintenance of the body's CoM is based on an internal model which is dependent on highly integrated multisensory information and is adaptive and flexible for a wide range of tasks. These sensory systems provide information to the central nervous system (CNS) about the position of the body segments relative to each other and the surrounding environment, which is known as proprioception. An unconscious representation of the body's configurations and dynamics is formed as an internal reference that the CNS can use as a reference frame to continuously restore the body's balance or its required orientation.

In a stable environment, the visual, somatosensory and vestibular systems provide convergent and redundant sensory information allowing for the control of balance. The CNS integrates all afferent inputs (visual, vestibular, somatosensory) into a single perception of the position of the body and limbs in the surrounding environment (Jeka et al, 2000). The CNS develops postural strategies to maintain balance that consider multiple parameters and occurs in a task specific and flexible manner (Jeka et al., 2000; and Scholz et al., 2007). However, life and sport are unpredictable and the sensory information being provided to the CNS is either unreliable or absent in many circumstances (ie. unstable surface). Based on this theory the idea of training or stressing our balance sensory systems has arisen in order to help the body continuously develop new strategies to be able to adapt to these perturbations and respond within a reasonable time frame to avoid losing balance.

1.2 Thesis Overview

The overall objective of this thesis was to define the relationship between single leg standing balance and ankle proprioception. The literature review that follows first outlines both the anatomy and physiology of the systems involved in postural control, with a specific focus on the somatosensory system's anatomy, central response, and areas of motor control. Secondly, measurement techniques used to determine proprioception contribution and postural sway are discussed, followed by reviews of literature involving the trainability of proprioception on various populations, and the current controversies that exist in the literature surrounding this topic.

2. Literature Review

2.1 Postural Control

Information about body position and its relative position in the environment is gathered by the somatosensory, vestibular and visual systems. Sensory information from the somatosensory, visual and vestibular systems is integrated at the CNS at three distinct levels of motor control. These three levels are the spinal cord, the brainstem and at higher brain centres in the cortex (Fitzpatrick et al, 2004). The focus of this document is on the somatosensory system and its relationship to balance, however all systems contribute to the overall ability of the body to maintain balance. It is therefore also important to identify the contributions of the visual and vestibular systems to balance.

2.1.1 Visual System

Information regarding one's position in their environment is picked up by the visual system and transmitted to the visual cortex via afferent fibers (Skinner et al., 1984). When standing the body naturally sways about the ankles and as a consequence shifts the visual field. The input from the eyes is used by the central nervous system to create a spatial map of the surroundings. The spatial map is used to assess the speed and direction of moving objects and to locate any potential hazards in one's path. One of the earliest developments of a balance assessment was the Romberg Test which was developed in 1853 by Moritz Heinrich Romberg. The Romberg test is a measure of standing stability, through the manipulation of vision and is reliant on intact proprioceptive and visual sensory pathways, the sensorimotor integration centres (cortex and cerebellum), and the motor pathways (corticospinal (pyramidal) tract). In 2004, Jansson and colleagues carried out a study that investigated the relationship between balance and vision. They showed that when vision was occluded, postural sway measured by one's center of mass trace increased 20-70% demonstrating the importance of visual information in postural stability.

2.1.2 Vestibular System

The internal ear plays a role in postural control, and consists of a series of bony cavities (bony labyrinth) and membranous ducts and sacs (membranous labyrinth) which can be found in the petrous part of the temporal bone. The structures in the internal ear convey information to the CNS about balance and hearing based on the movement of fluid within the ducts. The internal ear is able to sense directional changes in acceleration and rotation (Hegeman, 2005). This area within the middle ear that senses and plays a role in body equilibrium is referred to as the vestibular apparatus and is found in mammals bilaterally (Germann, 2002).

2.1.3 Somatosensory System

In many goal-directed movements, accuracy is dependent on the presence of visual and proprioceptive information, suggesting evidence for a dual model of motor control; feedback and feedfoward. Initial goal oriented movements are driven by a motor plan (feedforward control), however accuracy is dependent on sensory feedback loops that allow for corrections during the movement. The somatosensory system is a sensory system that consists of receptors and processing centres producing sensations of touch, temperature, pain and proprioception. Sensory information is detected from sensory receptors found in the skin, joints and muscles and serves as both a feedback and feed forward mechanism in the body which assists in daily function such as movement and balance. The sensory modality of interest in this thesis is proprioception. Human proprioception is dependent on the information gathered from muscle receptors (golgi tendon organs, and muscle spindles), cutaneous receptors, and joint receptors.

Each receptor functions independently and has its own role in the contribution to proprioception

2.2 Proprioception

Proprioception is derived from the Latin terms *(re)ceptus* (the act of receiving) and *proprius* (one's own) and is reliant on the sensory information collected within the central nervous system. Proprioception is representative of multiple sensory sensations that act on both a conscious and subconscious level which include:

1) The detection of position and movement of the limbs and or joints in space

2) The sensation of the effort, tension and heaviness accompanying muscular contractions,

3) The sensation of sensory information pertaining to the conscious distribution and timing of motor commands (Sherrington, 1906)

4) The sensation of the body and limb orientation in space (Gandevia et al., 2002).

2.2.1 Proprioception vs. Kinesthesia

The definition and scope of what is entailed in the term proprioception is not clear throughout literature. It is known that the control of posture and movement involves the integration of neural signals that can access one's consciousness and that the definition of consciousness involves the awareness of sensory information whereby the sensory information is accessible for verbal report. Bastian (1888) suggested that these consciously perceived signals are included within the terms 'kinesthesia' and 'proprioception' and that they arise from activity in mechanoreceptors, from centrally generated motor commands and interactions between the afferent and efferent signals. In 1906, Sherrington's initial conclusions about our sensory system had kinesthesia and joint position sense both being components of proprioception. Sherrington (1906) referred to kinesthesia as being the ability to sense movement in a body part, where position sense was defined as the ability to sense the location of a limb in space, as well as its orientation with respect to the body. For the purpose of this experiment, kinesthesia is defined as the perception of movement requiring conscious awareness that contributes to joint movement control and proprioception containing the component of kinesthesia as well as involving receptors that signal position or movement about a joint with or without reaching consciousness.

2.2.2 Muscle Receptors

Charles Bell stated that muscles contain sensory elements that together contribute to the conscious sense and awareness of one’s muscles and also to the subconscious reflexive control of movement (Bell, C, 1811). The muscle receptors that exist within our sensory system are: golgi tendon organs and muscle spindles.

Muscle Spindles

Muscle spindles are composed of 3-10 intrafusal muscle fibres which are encapsulated by connective tissue and are embedded and aligned parallel to extrafusal muscle fibres (Winter et al, 2005). Muscle spindles are stimulated by changes in the length and/or the velocity of a muscle. There are three types of intrafusal fibres; dynamic nuclear bag (Bag1), static nuclear bag (Bag 2), and nuclear chain (Winter et al, 2005). The response properties of the varying fibres within a muscle spindle are dependent on the fibre characteristics and are innervated by either primary (1a) or secondary afferent nerve endings. The nuclear chain fibres are intrafusal muscle fibres that are responsible for the detection of muscle length. The nuclei of the nuclear chain fibres (i.e., central portion where sensory axons wrap around the intrafusal fibers) are aligned in a chain and excite the secondary nerve. Nuclear Bag Fibres contain a large portion of nuclei concentrated in bags that cause excitation of both primary and secondary nerve endings. Bag1 fibres are innervated by dynamic axons and bag2 fibres are innervated by static axons. Each intrafusal muscle fibre contains 1-3 bag fibres, and the afferent nerve endings are spiraled around the central portion of the fibre. Primary and secondary afferent fibres spiral around intrafusal muscle fibres and terminate on the central portions of the fibres. When the muscle is stretched, muscle spindle activity increases and as a muscle shortens associated muscle spindle activity decreases (Westlake, 2007). The afferents are stretch sensitive and send out sensory information based on the stretch of the muscle (Westlake et al,, 2007). Each afferent fibre responds to specific stimuli. The 1a afferents provide information to the CNS regarding movement and changes in stretch velocity within the muscles whereas the secondary afferents provide information on the length of the musce (Westlake et al, 2007).

Muscle spindles are also considered to be fusimotor, meaning they have an efferent system provided through gamma efferents (Gandevia, 1996). The muscle spindle's intrafusal motor innervation comprises mostly of fusimotor axons (gamma motor neurons). Each fusimotor axon innervates several muscle spindles. There are skeletofusimotor axons (beta motorneurons) that can innervate both intrafusal and extrafusal muscle fibers. The gamma motor neurons only activate intrafusal muscle fibres, causing a contraction at the polar end portions of the intrafusal muscle fibres when activated, causing the spindle ends to contract, stretching the central region of the spindle. The stretching of the central regions of the spindle results in an increase in the firing rates of the afferent endings (Westlake, 2007). Similar to the sensory components of muscle spindles, the motor neurons are also classified as static or dynamic according to their pattern of innervations and their physiological effects. The static motor neuron axons innervate the chain or bag2 fibres, whereas the dynamic axons innervate the bag1 fibers that result in an increase in the velocity sensitivity of the 1a afferents (Westlake, 2007). The motor input of intrafusal fibers leads to an increase in the sensitivity of the muscle spindle to stretch (Westlake, 2007). Out of all the proprioceptive receptors, only the muscle spindle receives efferent input to modify the sensitivity of the receptors in the periphery (Westlake, 2007).

Through isolation techniques (anesthetization, nerve blocking, vibration and freezing techniques) research results have suggested that muscle spindles are the most important proprioceptor for movement control (Sherrington 1906; Goodwin et al., 1972; McCloskey et.al., 1983). The history of muscle spindles role in proprioception began with work done by Sherrington (1906), who postulated that muscle spindles had the most influence over proprioception, however went rejected for the first half of the century. In a series of landmark experiments throughout the 1970's and 1980's Sherrington's theory on the role that muscle receptors had on proprioception was reintroduced (Goodwin, 1972; McCloskey, 1983). The role of muscle receptors in proprioception was identified by Goodwin (1972) using muscle tendon vibrations to excite the primary muscle spindle afferents. The results of this research indicated strong illusions of position and movement at the joint when muscle spindles were artificially excited (Goodwin et al., 1972). Goodwin et al. (1972) drew conclusions that muscle spindles played a role in proprioception. Further research done by McCloskey et al. (1983) revealed that high frequency vibrations of muscle tendons were found to stimulate primary endings of muscles spindles causing for illusions of body sway, whereas vibrations at lower frequencies and larger amplitudes stimulated the secondary endings of muscle spindles providing an enhanced perceived static position of the limb (McCloskey, 1983). The research performed by Sherrington (1906), Goodwin et al. (1972) and McCloskey et al. (1983), outlined the primary importance of muscle spindles to proprioception and opened the doors for further exploration by researchers.

The importance of proprioceptive signals from lower leg muscle spindles to standing balance was investigated by Fitzpatrick and colleagues in 1994. Through methodologies of vision occlusion, sensory ischemia (anesthesia and use of ankle cuffs) and full body bracing, the role of the visual, vestibular and sensory receptors in the lower limb were examined. Through step by step isolation techniques it was concluded that visual information was necessary for maximal stability, cutaneous information from the feet and ankles did play a significant role in the maintenance of posture, and that during normal stance vestibular inputs were not responsible for modulating activity in the leg muscles to assist stability. However, it was found that when all isolation techniques were applied allowing for the lower limb muscle receptors to be the single sensory input for the control of ones stance and postural sway, the results revealed that proprioceptive signals from receptors in the leg muscles were solely sufficient in the maintenance of a stable upright stance.

Golgi Tendon Organs

Golgi tendon organs (GTOs) are another type of muscle receptor that are found along musculotendinous junctions in series with muscle fibres. GTOs are composed of serial strands of collagen which are connected to the muscle fibre endings. These endings are entirely encapsulated by a fibrous capsule (Marieb, 2001). The GTOs have a very low threshold and a high dynamic sensitivity which enable them to provide feedback regarding muscle tension during an active contraction or passive stretch (Germann, 2002).

Each GTO is innervated by a single type 1b sensory afferent fiber that branches and terminates by spiraling around the collagen strands. The 1b afferents are myelinated and large in diameter (Germann, 2002). As a muscle shortens (i.e. contracts) the 1b afferent deforms due to the moving collagen strands, resulting in the opening of stretch sensitive cation channels. The opening of the stretch sensitive cation channels results in a depolarization of the axon allowing for nerve impulses to be fired (Westlake, 2007). This impulse travels up the spinal cord synapsing with interneurons within the spinal cord, causing spinal reflexes associated with the ascending information. A common spinal reflex associated with GTOs is autogenic inhibition which regulates the force profile of continually contracting muscles (Gandevia,1996) Autogenic inhibition is a protective mechanism for muscles and tendons from excessive force. Ascending information from GTOs can also travel via the cerebellar spinal tracts up to the cerebellum and cortex for the regulation of movement.

GTOs are suggested to provide the principal afferent input for a peripherally derived sense of muscle tension (Gregory, 2002). They were first thought of as “overload protectors” firing when muscle force approached injurious levels (Prochazka, 1996). However, the idea of overload protectors being the only function was proven false when it was found that an adequate stimulus for GTOs was an active contraction of the motor unit in which the GTO was associated with, thus GTOs respond over the full range of muscle force and not only as overload protectors (Gregory, 2002).

2.2.3 Joint Receptors

There are four types of receptors in the joint capsule and ligaments: ruffini endings, pacinian corpuscles, Golgi tendon organ like endings, and free nerve endings (Johanssen et al, 2000). Each receptor is classified according to its ability to adapt to changing stimuli and their detection threshold. Ruffini endings are slow adapting and have a low threshold of detection for mechanical stress. They are sensitive to position change, intra articular pressure, amplitude and the velocity of joint movement (Proske, 1988, Ferrel, 1987). The Pacinian corpuscles are rapidly adapting and have a low threshold for detecting mechanical stress and are activated during changes in velocity (acceleration and deceleration). They are inactive during static positions and constant velocities. The GTO-like endings function to detect mechanical stress at high thresholds and are slow adapting and predominantly stimulated when a joint is at extreme ranges of motion (Kandel, 2000). Free nerve endings contain a large number of chemoreceptors which are activated when there has been damage or deformation that has occurred to a joint causing an inflammatory response (Marieb, 2001).

The role that joint receptors play in proprioception has been debated throughout literature. Proske et al. (1988) reviewed the roles that joint receptors play in proprioception. The first experiments that investigated joint receptors examined the ability of the joints of a cat to signal position (Boyd & Roberts, 1953; Skoglund et al., 1956). Their conclusions were that cats were able to detect joint position from joint signals. Later studies challenged these earlier findings by introducing the idea that joint receptors act as a range limit detector as opposed to a position detector (Burgess & Clark, 1969; Clark & Burgess, 1975). The idea of joint receptors playing a role as range limit detectors was accepted up until the 1980s when Ferrel (1980) argued for a return to the traditional view, with joint receptors playing a role in proprioception and not just as range limit detectors. In spite of this, a study performed by Clark et al. (1989) who's team showed an increase in the activity of the joint receptors at extreme ranges of motion, with little to no activity in the mid ranges of movement seen in the knee, elbow and hip joints rejecting the traditional view of joint receptors signaling joint motion, and in support of joint receptors acting as range limit detectors.

Although the direct role of joint receptors on proprioception is unclear and debated in literature, their role in gamma motor neuron activation has provided more clarity. Gamma motor neurons have been found to be excited by joint afferent receptors resulting in an increase in muscle activation (Johansson et al.,1981; Johansson et al., 1989, Sojka et al., 1989; Johansson et al., 1991). A study performed in 1981 by Johansson and colleagues found that the reflexive control of gamma motor neurons was found to be mediated by a single pulse of a joint nerve; the posterior articular nerve (PAN) (Johannson et al., 1981). This study was one of the first to link joint receptors to gamma motor neurons. Later experiments performed by Johansson and colleagues followed an earlier hypothesis which was made by Freeman & Wyke in 1967, which hypothesized that joint receptors may contribute to the regulation and coordination of muscle tone and stiffness around the joint by means of a gamma- spindle loop. Support for Freeman & Wyke's earlier hypothesis was provided by this study performed by Johnasson et al., 1989 and Sojka et al., 1989. Johansson and colleagues (1989) examined the reflexive effects of repetitive electrical stimulation of the PAN and manual compression on the knee joint and found that this stimulation could influence the responses of primary muscle spindle afferents (Johannson et al., 1989). Sojka and colleagues recorded the activity of two to four primary muscle spindle afferents from anaesthetized cats. Through stretching of the posterior cruciate ligament of the ipsilateral limb the researchers saw a change in the dynamic and static sensitivity of the afferents to the stretching technique employed indicating that the joint ligaments reflexive action may play on the gamma motor muscle spindle system (Sojka et al., 1989). The above studies show support for the influence of joint receptors to the gamma motor neurons and subsequently the muscle spindle afferent discharge.

An increase in gamma motor neuron activation caused from joint receptors heightens muscle spindle activity. The increased sensitivity of the muscle spindles caused from gamma motor neurons being activated by joint receptors allows for muscles to remain stiff. A stiff muscle is the ratio of change in force per change in length. Stiffness is dependent on intrinsic and extrinsic (reflex) components. The reflexive control of muscle stiffness is a result of increased reflexive neural activation of the muscle determined by the excitability of the motor neuron pool which in turn is dependent on the sensitivity of the primary muscle spindle afferents which elicits reflexes. Damage to the joint receptors would result in a reduction of stiffness both in the muscle and joint. Freeman and Wyke (1967) suggested that functionally unstable feet and ankles are a result of muscular incoordination caused from damage to the joint receptors (Freeman and Wyke, 1967). This damage to joint receptors is hypothesized to cause an increase in joint laxity, and a below normal protective reflexive response (Freeman & Wyke, 1967).

2.2.4 Cutaneous Receptors

Cutaneous receptors are found within the skin and detect mechanical deformations such as pressure and stretch on or of the skin. This allows for the perception of joint position and movement based on the tightening or loosening of the skin (Refshauge, 1998). There are slow adapting and rapidly adapting receptors in the skin. The receptors are classified according to the sensory receptor ending (Westlake, 2007). These consist of: type 1 (SA1) merkel disk receptors, type 2 (SA2) ruffini endings, and type 3 (SA3). The latter has recently been found to have the most contribution of the cutaneous afferents on proprioception (Westlake, 2007). The receptors considered to be rapidly adapting receptors respond to touch and vibration and are termed the meissner corpuscle (FAI) and pacinian corpuscles (FAII).

It was not until recently that research confirmed that cutaneous receptors play a direct role in proprioception (Johansson et al., 1996). This inference was made by two separate groups of researchers who stimulated cutaneous receptors in the finger (Burke et al, 1982; Johansson et al., 1996). They found that participants felt like their fingers were moving even though the digits were immobile. These results support the argument that these receptors directly contribute to proprioception (Collins & Prochanzka, 1996; Johansson et al, 1996). Anaesthetization experiments have also examined the contribution that cutaneous receptors have on proprioception (Gandevia & McCloskey, 1976; Refshauge et al, 1998). When the finger is numbed, there is a decrement in movement detection which suggests that cutaneous receptors play a role in proprioception in the finger joint. Collins and colleagues (2005) provided the first evidence suggesting a link between cutaneous receptors and proprioception in areas other than the hand. They concluded that cutaneous receptors could generate proprioceptive senses in both the elbow and the knee joints.

The literature seems to support the case that a relationship between cutaneous receptors and proprioception exists (Collins & Prochanzka, 1996; Johansson et al, 1996). Given this information, consideration should be made for the contributions that these receptors have when examining proprioception at the level of the joint. Based on the reviewed literature cutaneous afferents may play a role in standing balance control, serving as a sensory input to the CNS regarding changes in foot pressure and skin stretch as the body moves to maintain balance.

2.2.5 Receptor Review

In review the human body consist of numerous sensory systems (vestibular, visual and somatosensory) that aid in the maintenance of postural stability/balance. The integration of these systems is highly complex within our central nervous system. The system of importance in this document is that of the somatosensory system and its array of receptors (muscle, skin and joint) all of which play independent and integrated roles providing proprioceptive information. Within the skin, muscle, bone, joint ligaments and joint capsules are afferent nerves (also referred to as mechanoreceptors); however, not all of these components contribute equally to proprioception (Refshauge, 1996). Muscle spindles have been found through isolation techniques and vibration to have a strong role on the control and sensation of postural sway (Sherrington, 1906; Goodwin et al., 1972; McCloskey et al., 1983; Fitzpatrick et al., 1994). Golgi tendon organs were found to act as range limit detectors along with an indicator of muscle tension and force (Gregory et al., 2002). Cutaneous afferents as indicators of movement detection and correction (Ferrel et al., 1987) and joint receptors as range limit detectors (Clark et al., 1989). The sensory information picked up from each of these receptors is integrated within our central nervous system to provide an overall image of the body and its surroundings.

2.2.6 Areas of Motor Control

Sensory information received from the muscles, cutaneous and joint receptors enters the spinal cord through the dorsal roots, passes through the ipsilateral white matter of the dorsal columns and ascends up the dorsal column of the medial lemniscus pathway which then directs the sensory information to the appropriate supraspinal level of motor control. Peripheral information also travels via the spinocerebellar tracts conveying information to the two associative areas; cerebellum and basal ganglia that regulate the motor commands and coordination of the movement (Refshauge et al, 1995).

As the sensory information passes through the brainstem the information is relayed through the medulla which is where these primary afferents synapse onto secondary afferents that then decussate and ascend contralaterally, traveling rostrally to the thalamus. From the thalamus, the neurons project to the primary somatosensory cortex in the postcentral gyrus. Prior to reaching its final destination at the somatosensory cortex, the sensory information is filtered at the brainstem, thalamic and cortical levels for irrelevant and redundant input (Johansson, 2000). The collecting or filtering of redundant and repetitive information picked up from the peripheral afferent receptors within the brainstem is referred to as ensemble coding. The ensemble of afferent information passes along information based on overlapping range of sensitivities to the same stimuli, providing a highly specific signal sent to the cortex (Johansson et al., 2000).

2.2.7 Final Common Input Theory

The information provided by the muscle spindle afferents is formed by not only variations in muscle length but also by descending pathways from ipsilateral and contralateral peripheral sensory inputs. Peripheral inputs arising from the sensory receptors throughout the body (muscle, joint and cutaneous) and descending efferent signals from the CNS are believed to be integrated with the fusimotor system. Johansson has referred to this theory as the “final common input theory” (Johansson, 1991). The final common input theory suggests that the combined signal (ascending afferent and descending efferent signals) is subsequently relayed to the muscle spindle for final integration with input arising from the length and velocity changes of the muscle. Information from the receptors is transmitted and fitered first at the brainstem level, where the information is filtered, and it is here in the brain stem where the gamma motoneurons reside and have direct projections to the muscle spindles. The information received within the brainstem modulates the descending efferent response by the gamma motorneurons to the spindle, either by increasing or decreasing its firing rates.

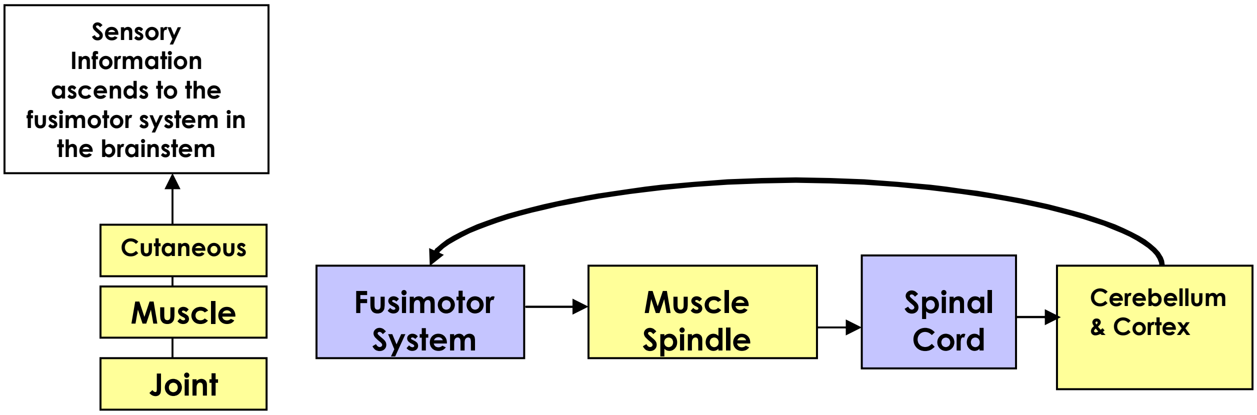

Figure 1- Common Input Theory

Figure 1 is a schematic of the final common input theory. Sensory information detected from the muscle, skin and joints ascends up the spinal cord to the fusimotor system within the brainstem. The fusimotor system then relays a descending efferent signal to either increase or decrease the firing rate of the muscle spindle; this information then ascends up the spinal cord to the CNS.

2.2.7 Receptor Contribution to Balance

During quiet stance the projection of the centre of mass falls within the body's base of support, requiring only minor adjustments at the ankle to maintain body position and balance (Gatev, 1999; Winter, 1995). As stance transitions to a single leg, staggered leg, narrowed stance or to gait, adjustments within the body must be made in order to maintain the body's centre of mass within the limits of the supporting surface. Many physiological processes come into play to maintain body stability such as contraction of the trunk musculature and increased reliance on sensory feedback strategies. All processes rely on sensory receptors in the body in order to provide accurate information on the state of the body and serve as a constant source of feedback in order to maintain stability.

Upright stance has been modeled as a single joint inverted pendulum, pivoting at the ankle joint. The balance control strategy primarily used during non-perturbed standing was suggested by Gatev et al. (1999) to be the ankle strategy. They suggested that the common use of the ankle strategy occurred due to an increased need to focus on ankle proprioception to control the body's movements (Gatev et al., 1999). Medial and lateral sway has been found to be controlled and corrected at the ankle by invertors and evertors, as well as from the hip adductors and abductors (Day et al., 1997). Adjustments for posture made at the ankle joint are sensory driven in order to correct posture and are strongly dependent on the sensory information that is being received. When controlled movement or stance is perturbed, the body will tend to sway, when the body sways, lower limb and postural muscle activity increases as the body attempts to maintain the state of balance (Nardone et al., 1997). The perturbation is detected by peripheral receptors throughout the body, relaying information to the spinal cord for rapid reflexive adjustments and to the supraspinal level for more specific corrections. This increase in muscle activity is driven by an increase in sensory information being transmitted to the CNS, or through reflexes within the spinal cord.

2.3 Central Response and Contribution to Proprioception

2.3.1 Attentional Demands of Postural Control

The importance of both the sensory and motor systems has been identified for postural control; however the attentional demands and the allocation of cognitive resources during postural control should also be discussed. As the postural demands of a task are increased, there is a decrease in attentional capacity. In experiments involving a dual task paradigm, the ability to maintain postural stability is considered the primary task and the secondary task would be a cognitive task or reaction time task measured by the success or accuracy of the task. Commonly a decline in performance is seen when one is subject to a postural and cognitive/reaction time task (Teasdale et al., 2001; Redfern et al., 2001; Condron & Hill, 2002; Pellecchia, 2003). Mitra & Fazier tested this hypothesis by examining a dual task paradigm which instructed participants to either divide their attention equally on a balance task and reaction time task, or unequally with more attention on the reaction time task. Results of this experiment revealed less postural sway when attention was divided equally between the two tasks (Mitra& Fazier, 2004). Results of Mitra & Fazier's study indicated that specific allocation of resources must be specifically stated to the participants, as well that provide support that attention does play a role on balance performance (Mitra and Fazier, 2004). The importance in understanding the limited capacity of our attention when carrying out dual task paradigm experiments is essential.

2.3.2 Sense of Effort

Proprioception provides sensory information on the orientation and location of the limbs in space, serving as a feedback mechanism within the body. However, proprioception is not solely dependent on peripheral afferents (joint, cutaneous, and muscle), but also on centrally generated motor commands in order to provide information on exactly what is taking place within a given limb (Walsh, 2005). The centrally generated motor commands that are associated with one's sense of effort to perform a task are derived from motor output commands required to perform voluntary contractions, resulting in the knowledge of limbs and body orientation in space (Walsh, 2005). The concept of sense of effort is often attributed to the output of the motor command generated by the CNS, however an accurate generation of one's sense of effort requires both knowledge of the output motor command as well as ascending proprioceptive information.

In order to assess the magnitude of proprioceptive contributions to one's sense of effort, Lafargue et al. (2003) examined a contralateral hand matching task in a healthy control group and compared them with a deafferented participant. Deafferentation results in an absence in interaction between motor and proprioceptive information providing difficulty in the performance of many motor tasks. Results of Lafarque et al.'s study showed that both the deafferented (participant known as GL) and the control participants could maintain a constant relationship between the force exerted by the control hand and the force exerted by the experimental hand (Lafarque et al., 2003). It was found that the deafferented participant was able to maintain this result throughout all trials without the knowledge of the perceived effort taken to accomplish the task (Lafarque et al., 2003). From these results, Lafarque et al. concluded that the control group used proprioception to perceive a sense of effort in order to perform the contralateral matching task. However, it was inferred that GL carried out the tasks via one of two ways; through an indirect perceived muscular force via central effort, or a reliance on a memorized motor command of the reference hand (Lafarque et al., 2003).

Centrally generated sense of effort in the absence of proprioception has been further examined by Gandevia et al. in 2006. This group investigated centrally generated sense of effort in the absence of peripheral inputs using ischemia induced paralysis and anesthesia of the hand and arm. Participants were instructed to match six wrist positions under three conditions: rest, 30 degrees flexion, and 30 degrees extension (Gandevia, 2006). The results showed that participants misperceived their limb position by over 20 degrees in either direction

(Gandevia, 2006). Gandevia concluded that afferent input is essential in the calibration and scaling of the sense of effort (Gandevia, 2006). Similarly, Winter et al. (2005) performed a series of experiments in order to investigate position sense in the absence of vision (Winter et al., 2005). They hypothesized that without visual information, peripheral inputs and signals from central origin will give rise to a sense of effort (Winter et al., 2005). They found that when one arm was supported by an external device, the ability to accurately match the limbs increased (Winter et al., 2005). When unsupported, there was a decrease in the proprioceptive acuity at the elbow joint (Winter et al., 2005). When a load was added to the testing limb there was an increase in error during the matching task. Winter and colleagues attributed this increase in error to an increase in the sense of effort (Winter et al., 2005).

Each of these studies concluded that in the absence of afferent input the CNS has the ability to generate central effort; however, the internally generated signals that relate to the size of motor commands may need to interact with afferent input to gain full access to our consciousness (Gandevia et al., 2006; Lafargue, 2003; Winter, 2005).

2.4 Measurement of Proprioception

Proprioception is typically assessed in one of two ways. The first is to determine the threshold at which passive movement (TPM) is detected. The second is the ability to match joint position also referred to as joint position sense (JPS). JPS and TPM are commonly used measures to establish the accuracy with, or threshold at which, an individual can detect joint position and movement (Arnold, 2006). A common method used to assess the role of proprioception on balance is through the removal of proprioceptive information from the moving joint. This has been done by reducing cutaneous information by way of anesthetizing, blockage of circulation, freezing, or by reducing joint and muscle involvement (Konradsen, 1993).

2.4.1 Threshold to Perception of Passive Movement

The threshold to passive movement (TPM) represents the degree to which a joint can be passively moved and in turn, the participant's ability to have a conscious awareness of that movement. TPM involves passive joint rotation at a rate less than one degree per second. During TPM participants are asked to press a switch to stop motion either at the moment of the perceived movement or once they can determine both the occurrence of movement and directionality (Westlake, 2006) The test re-test reliability of TPM testing has been assessed and it has been found to be a valid and reliable means of measurement (Deshpande, 2003). When testing for threshold, the experimenter must ensure that low testing velocities are used. Low testing velocities allow for a precise representation of the existing ankle rotational velocities observed during quiet stance. The speed chosen for TPM must be at a functionally relevant threshold for maintenance of upright posture (Westlake, 2006). This protocol relies on the response time of the participant to trigger the finger switch to indicate a perceived movement. This time has been identified in previous literature as ranging from 185-240 ms in young to older adults (Madhaven, 2005). Included in the response time is the time for central processing time and finger trigger time (Madhaven, 2005).

2.4.2 Joint Position Sense

Joint position sense (JPS) involves passively and actively moving a joint to a pre-determined test angle. For example, a participant's ankle would be positioned at a specified angle, held at this angle for five to seven seconds and then brought back towards the original start position (Westlake, 2007). Participants are then asked to match the position either through passive (i.e., when the ankle is moved by the experimenter, and participants indicate when ankle reaches target position) or active movements (i.e., participant actively moves their own ankle to target position) (Westlake, 2006). When JPS is measured using a matching task the results are often expressed as an absolute error (AE). AE will identify the magnitude of the JPS, representing an individual's overall ability to reproduce a joint angle. AE has been reported in the literature as an accurate, reliable and precise measurement for JPS (Westlake, 2007).

2.4.3 Body Position

As one goes from a sitting to a standing posture, the transmission of afferent inputs from the lower limb to spinal and supraspinal sites is altered (Applegate, 1988). As the body equilibrium changes (i.e., sit to stand, stable to unstable) transmission of this somatosensory information on posture being relayed to the cortex is altered and adjustments in the CNS take place (Kiefer et al, 1998; Stillman et al., 2001; Westlake, 2007). The understanding of these alterations in the transmission of afferent inputs based on the position of the body is important for the assessment of proper proprioceptive testing measures. Applegate et al., (1988) showed that the transmission of somatosensory information to spinal and supraspinal sites regarding posture is altered based on the position of the body (Applegate et al., 1988).

The ability of our CNS to gather and relay proprioceptive information has also been found to be dependent on the body's position. Evidence presented by Kiefer et al., (1998) suggested that the proprioceptive test results of TPM and JPS are dependent on whether the body position is weight bearing or non weight bearing, with the results indicating lower JPS and TPM results in weight bearing positions compared to non weight bearing. However, Refshauge and colleagues (1998) found no difference in a young population for TPM measures when participants were in a seated knee extended position and standing position, however thresholds were increased when the testing knee was flexed while seated (Refshauge et al., 1998). Refshauge and colleague's results suggest that the threshold was dependent on the activation of the lower limb muscles causing an increase in the muscle spindle's discharge (Refshauge et al., 1998). Westlake (2007), replicated the study performed by Refshauge using both a young and older population (70-87yrs) using three testing positions (seated knee flexed, seated knee extended, and standing). Results of Westlake's work also disproved Kiefer's earlier work, indicating that the use of TPM and JPS for proprioceptive testing at the ankle was not dependent on testing position for the older population, but was dependent on load and activity on the lower limb muscles.

The body position of importance in this study is that of a weight bearing unipedal/ single leg stance. In humans during single leg/unipedal stance the centre of mass drifts in the horizontal plane (medial to lateral). In order to maintain balance due to this drift our CNS requires fast and precise sensory information in regards to the rapidly occurring torques taking place at the ankle, as well as the exact location of the centre of pressure under the foot. Sensation of these movements taking place at the foot requires that our afferent receptors detect proprioceptive information at low thresholds in the ankle, providing early information regarding the direction of movement of the lower leg. Once the sensory information is relayed to our CNS and interpreted, the CNS responds with an efferent signal causing a counteracting ankle torque that is necessary to counteract the original movement and to maintain balance.

2.4.4 Changes to the Measurements of Proprioception

Due to ageing, injury and neuromuscular disorders proprioception can become compromised, diminished or non-existent in the limbs. The loss of proprioception can cause the inability to regain balance, and loss of coordination and control of limbs with the removal of sensory information (ie. vision). Understanding the deficits that can occur are important in the understanding of the functioning and processing of proprioceptive information.

Ageing

Balance control is known to decline with age, resulting from impairments in the sensory, motor, and central processing systems. Some of these impairments may be caused from a decline in function or pathology related to one of our three sensory systems (visual, vestibular and somatosensory). The integration of the sensory information collected from the three sensory systems has also been stated to be compromised with age (Westlake, 2007). Evidence suggests that there are changes in the central processing mechanism causing a problem in the integration of sensory information and a decrease in the ability to compensate for unreliable or discordant sensory inputs (Westlake, 2007).

As humans reach advanced ages (>80years), proprioceptive inputs are no longer reliable, and a dependency on vision arises (Camicioli et al., 1997). Both the visual and vestibular systems play a role in balance control showing a decline in function as we age (Lord & Ward, 1994). The visual system provides a spatial reference of our environment, providing a mechanism for navigation through the world. It is known that vision declines following the age of fifty causing a potential decrease in visual acuity, contrast and glare sensitivity, adaptation to the dark, and a decrease is depth perception and accommodation (Sturnieks et al., 2008). With a decrease in vision, balance control and object avoidance becomes impaired, causing an increased need to have precision of the two remaining sensory systems in order to maintain balance. The vestibular system detects position and movement of the head (Fitzpatrick, 2004). Impairments of the vestibular system may be caused by direct trauma, infection, calcium carbonate deposits in the semicircular canals, cerebellar ataxia and from an autoimmune disease, all disorders seen to be more prominent in the ageing population (Sturnieks et al., 2008). Also with age there is a known attrition of neural and sensory cells in the peripheral labyrinths. All pathologies can cause obvious impairments in gait and posture (Sturnieks et al., 2008).

The somatosensory system has a structural and functional decline with age, which can lead to an increase in postural instability (Lord & Ward, 1994). The proprioceptive thresholds in the perception of the centre of pressure of the foot velocities are lower than those seen in the visual and vestibular system, indicating the high importance of the somatosensory system in balance control (Menz et al., 2005). Ageing may cause changes within the muscle spindle, such as a decrease in the number of intrafusal fibres, an increase in the capsule thickness, both which can cause impairments in the static and dynamic sensitivity of the spindles (Sturnieks et al., 2008). Ageing has also been found to show a decrease in Pacinnian and Meissner receptors, causing a corresponding decrease in the sensitivity to vibration perception, and touch thresholds (Sturnieks et al., 2008). The tactile sensations received from the sole of the foot provide information on the force distribution during weight bearing activities. The decrease in tactile sensitivity is shown to be predominant in ageing adults and is correlated with a decrease in balance performance (Menz, 2005). Joint position sense also decreases with age, and was first discovered by Laidlaw & Hamilton (1937) showing that those in an age group of 17-35 had an increased performance in the detection of movement in the hip, knee and ankle then those in the age group of 50-85 years. Based on the above research there is a decline in the function of the somatosensory system as one ages, which can cause a detrimental effect on ones balance and movement abilities.

Injuries

Ankle stability is important in whole body function, movement and for injury prevention. Ankle injuries are the most common injury across numerous sports and are often at a higher risk for re-occurrence due to the function of the joint (Verhagen et al., 2004). The sensory afferents of the ankle have been shown by Konradsen et al. (1993), Hertel et al. (1996) and Westlake et al (2007) to play a role in the standing balance, and ankle proprioception. With the knowledge of the role that ankle receptors (muscle spindles, GTOs) play in ankle proprioceptive tests, it is necessary to gain a better understanding of the relationship between standing balance and ankle proprioception. One's balance and level of proprioception at the ankle have been suggested to play a role in the rate of injury at this joint. A study performed by McGuine et al. (2000), examined a group of high school aged basketball players. McGuine and Colleagues assessed each athlete and provided them with a balance score, based on the amount of sway that took place during a single leg balance task both with eyes open and closed (McGuine, 2000). The researchers then examined the rate of ankle sprains throughout the basketball season. The results of their research showed those with a high balance score had a lower rate of ankle sprains throughout the season when compared to those with lower balance scores, concluding that ones balance can be a predicative mechanism for one's susceptibility to ankle injury (McGuine, 2000).

Common measures of proprioception at a joint, and rate of injury prevention often requires the assessment of the ankle joint. Both Konradsen et al. (1993), and Reiman et al., (2004) examined the effect of anesthetization of ankle ligaments during a proprioceptive test. Both the anesthetized and non-anesthetized groups showed that when the lower limb muscles were active during an assessment of postural sway while standing (Reiman, 2004) and during an active inversion test (Konradsen, 1993), anesthetization had no effect on the proprioceptive sense of the ankle. However in Konradsen et al.'s (1993) study, results of the anesthetized ankle during a passive ankle inversion test showed a decrement in the ability to sense the inversion between the anesthetized and non-anesthetized ankle. This decrement was explained by Konradsen et al. (1993) to be due to the inactivity of the lower limb muscles during the passive test, thus lacking additional sensory information to aid in the performance. Hertel et al. (1996) took the two preceding experiments and further examined the effects of ankle anesthesia on one's single leg stance ability while manipulating vision. Results of this study demonstrated that after anesthetization and the removal of vision, each participant's centre of pressure caused increased lateral sway during static conditions and increased medial sway during dynamic conditions. This would suggest that there is a higher reliance on somatosensory input of the ankle when vision is removed (Hertel, 1996).

Research on ankle acuity has mainly focused on the prevention, treatment or explanation for ankle sprains or ankle instability (Hertel, 1996; Rozzi, 1996). Injury to the ankle ligaments has been found to cause partial deafferentation causing chronic ankle instability and was found to decrease single leg stability (Freeman & Wyke, 1964). They also concluded that associated with the loss of sensory afferent input from mechanoreceptors within an injured ankle is a decrease in the postural reflex responses in the body. Rozzi et al., (1996) have related balance training to an increase in postural stability for individuals with a history of ankle sprains. Prior to this, Konradsen et al. (1993) examined the effects of ankle proprioception on peroneal muscle reactivity and single leg balance. The experimenters assessed participant's ankle proprioception and balance by comparing it to an anesthetically blocked ankle's proprioception and balance. The results of the study showed there to be no significant difference between an anaesthetized ankle and a normal ankle in regards to one's ability to balance and their ability to sense active or passive positions of the ankle (Konradsen, 1993). Results of the above research indicate that the stability of the ankle is dependent on intact ligaments and reliable sensory information; however the detection of movement at the ankle through active or passive means was not correlated to stability at the ankle.

2.5 Balance and Proprioception

2.5.1 Measurement of Postural Sway

To better understand our proprioceptive system and its effects on the control of posture it is important to understand the parameters in which postural sway can be measured. Postural sway is assessed in research in order to gain a better understanding of the sensory and motor components associated with balance, assess age related changes and as a fall risk assessment. Postural sway can be measured using quiet stance as well as during perturbed stance.

Quiet stance is measured by subjects having their arms at their sides and feet most commonly side by side either placed together or shoulder width apart. Postural sway during quiet stance is measured based on the displacements of centre of mass (COM) or centre of pressure (COP) using a force plate. COM is the point in space at which the mass of the body is located, and has been represented by using its angular displacement and velocity. COP is the point of the body that is in contact with the support surface upon which the ground reaction forces are acting on and the results are derived from ground reaction forces recorded on a force plate and quantified in terms of length of the COP trajectory, mean of the COP velocity as well as the maximum and/or standard deviation of the COP amplitude in the anterior/posterior or medial/lateral planes (Karlsson & Frykberg, 2000). Velocity of COP allows for the determination in the frequency of postural corrections (Karlsson & Frykberg, 2000).

Perturbed stance in regards to measurements of postural sway allows for researchers to examine one's postural control strategies, and the role of various sensory systems throughout the body in the restoration of balance. Perturbations may be presented to the body by way of internal perturbations (rising of arms, bending at the waste, or a full body lean to the limits of the base of support). Perturbations may also be presented by way of external perturbation involving; movements of ones centre of mass through platform translations or through alterations of one sensory environment (vibration, manipulation of support surface). When perturbed in a laboratory setting participants are instructed to remain as still as possible while standing, thus when perturbed an ankle and/or hip strategy is employed in order to restore equilibrium.

2.5.2 Postural Balance Training

Balance training is the physical training involving internal and external perturbations to our body which challenge our motor and sensory systems. Balance training has been emphasized in the literature for its rehabilitative qualities, improved balance performance and more recently in the prevention or decreased rate of joint injuries and increased athletic performance. A common measurement of the effectiveness of balance training is based on one's ability to perform a balance task (e.g. single leg stance, or quiet stance on foam) and the reduction of a participants sway associated with this task (Kollmitzer, 2002). The results stemming from balance training (improved balance, decreased rate of joint injuries, and increase athletic performance) has been stated to be linked to improvements in proprioception, however as you will see in the below sections this has been a debatable statement (Verhagen et al., 2004; Clark et al.,1993).

2.5.3 Balance Training and Balance Improvements

Balance training requires sensory manipulation (visual, vestibular or somatosensory). Taube et al. performed a study in 2007 which investigated cortical excitability and the site of adaptation responsible for improved stance stability following balance training (Taube et al., 2007). Neural adpatations in the experiment was carried out through use of the use of H-reflex stimulation, TMS, and conditioning of the H-reflex (Taube et al., 2007). Results of Taube's study showed that improved balance performance as a result of balance training was due to supraspinal adaptations (Taube et al., 2007). Balance training as it is suggested in the name has been linked to improved balance performance or decreased postural sway (Paterno et al, 2004; Hain et at, 1999). A recent study performed by Paterno and colleagues in 2004 found that a six week balance training program decreased the incidence of ACL injuries in young female athletes as well showed an increase in their postural and single limb stability performance (Paterno et al., 2004). Similar results were seen in a study involving an elderly population performed by Hu and colleagues (1994) where elderly participants were randomly allocated to either a no balance training or a balance training protocol (five times/week for two weeks) (Hu et al., 1994). Following the two week training period the balance training group showed a decrease in sway when standing on foam, with their head extended and their eyes closed compared to the control population showing support that balance training can improve balance performance (Hu et al, 1994).

There are many sports (ballet, figure skating, martial arts etc.) that rely predominantly on a strong ability to balance. Sports requiring balance and precise integrated movements often outside of one's base of support such as T'ai Chi, challenge the sensory systems in the body, and to master these sports it requires a strong ability to balance. A study performed by Hain et al. (1999) investigated the effects of the practice of T'ai Chi on one's balance performance (Hain et al, 1999). Twenty two participants considered of having a mild balance disorder participated in this study and examined and assessed pre- and post T'ai Chi practice by means of a moving platform posturography, Rhomberg, and a reaching test (Hain et al., 1999). Results of Hain's study showed that T'ai Chi training did show a significant improvement from pre to post test (Hain et al., 1999). Results of the above study supports the notion that balance training does cause increases in participants balance performance, however does not indicate the cause of these improvements.

2.5.4 Balance Training and Injury Prevention

Research has revealed studies supporting balance training and its effects on injury prevention or rehabilitation (Malliou et al, 2004; Bahr et al.,1997). Malliou et al., (2004), investigated the effects that a two-week balance-training program had on injury prevention for female soccer players. The overall results showed a significant decrease in lower limb injuries throughout the season, providing support for the argument that balance training decreases the rate of injuries (Malliou, 2004). A similar study performed by Bahr and colleagues found a 49% reduction in ankle injuries throughout a volleyball season following a pre-season injury prevention and balance training program (Bahr et al., 1997). Vernhagen et al. (2004) states that ankle sprains are the most common injury in a variety of sports, and through experimentation Vernhagen and colleagues found that by incorporating a balance training paradigm the reoccurrence of ankle sprains are significantly reduced among athletes (Verhagen, 2004).

2.5.5 Balance Training and Improved Athleticism

To assess the performance measures with balance training, we can look at a recent study performed by Heitkamp et al. (2001), who examined the effects that a 6-week balance training program had on knee flexor and extensor strength in comparison to a six week resistance training program (Heitkamp et al., 2001). Participants in the balance training group performed exercises using a trampoline, stability ball and balance board, whereas the strength-training group performed their training on a leg press and leg curl machine (Heitkamp et al., 2001). Each group was pre- and post tested for single leg balance, stability on a tilting platform and for isometric strength using and isokinetic device on each lower limb (Heitkamp et al., 2001). Both groups showed a gain in muscular strength in each limb, but also a gain in balance was seen for the balance-training group indicating the effectiveness of balance training on both balance performance and strength gains (Heitkamp et al., 2001). To further examine the effects of balance training on athletic performance we turn to two recent studies performed by Gruber & Gollhofer (2007), and Myer et al. (2006). Results of each of these studies revealed that balance training has shown to be as effective as plyometric and ballistic training for improvements in lower limb muscular strength and recruitment patterns, as well as an increased vertical jump performance (Gruber & Gollhofer, 2007; Myer et al., 2006). These studies indicate that balance training does not only improve the reactivity and coordination to postural disturbance, but also modulates the CNS's motor response to better recruit muscle fibres for improvements in power and force initiation (Gruber& Gollhofer, 2004).

Results of the above experiments have revealed that balance training induces adaptations in all sensory systems assisting postural and motor control allowing for improved integration of sensory information and muscle fibre recruitment specific for the initiation of movement skills. Improvement in balance has suggested to be caused from one or all of the following factors: improved proprioception, generation of pre-programmed motor responses, and potential improved awareness and attentional focus on the balance task.

2.6 Proprioception Improvements

The ability to enhance proprioception has been shown to be plausible, however, it has not gone stated without debate. It has been suggested that improvements in proprioception could potentially take place at the sensory receptor level, or through a possible improvement in attention allocation, both of which will be discussed in the sections below.

2.6.1 Muscle Spindles

As mentioned previously when discussing the physiology of the muscle spindles, muscle spindles have the unique property in which they can be modulated with motor input. This modulation of motor input has been demonstrated by a reduction of spindle discharge in the absence of fusimotor drive. Due to the properties of the muscle spindle and its modulation with the fusimotor system it is plausible that proprioception could be enhanced by means of the fusimotor system. To support this claim individual nerve fibers are required to be examined. A study performed by Ribot and colleague in 1986 found there to be modulation of activity of the fusimotor system during non-motor tasks (ie. speaking, viewing a persons entrance to a room, sound of clapping), suggesting that the fusimotor system can occur independent to alpha-gamma coactivation (Ribot et al., 1986). With the consideration of the prominent role that muscle spindles have on proprioception along with the results seen in Ribot's study it appears that it may be possible to train proprioception. However, there is no evidence to suggest that increased fusimotor activity will result in a direct change in the output from muscle spindles providing an increase in position and movement sense.

2.6.2 Attentional

Research has suggested that individuals may be able to increase the attention paid to proprioceptive cues, resulting in increased balance performance (Ashton-Miller et al., 2001). When learning a new skill or task such as one requiring balance one goes through the various stages of learning, with the initial stage being the cognitive stage requiring increased attention for successful performance. Once the skill progresses to becoming more automatic the attentional demand is decreased. Based on this theory, as one improves their balance performance it may be due to one being more attentive to proprioceptive cues, and as exposure is repeated one attains an enhanced ability to monitor these cues at a subconscious level, otherwise known as procedural learning (new motor task mastered in the absence of attention)(Ashton-Miller, 2001).

2.6.3 Controversy of Training Proprioception

Balance training and proprioceptive training are terms that have often both been used interchangeably (Gauchard, 1999). Balance training has been shown to cause improved balance performance, a decreased rate in joint injury during a sport season, while at the same time proprioception is known to play a role in joint stability and whole body balance, but the assumption that balance training will improve proprioception is unfounded. Improvements in balance performance based on current literature cannot be attributed to improvements in proprioception, however it has been suggested by Clark in 1993 that improvements in balance, and decrease rate of injury, may possibly be due to a reorganization or new interpretation of multisensory information allowing participants to react and respond faster and more accurately to new unstable stimuli (Clark, 1993).

Research carried out by Verhagen et al. (2004) examined the effects of a balance board training program aimed at increasing ankle proprioception which they hypothesized would result in a decrease in the reoccurrence of ankle sprains. The results of their study showed that the addition of a balance board training program is a promising way to reduce ankle sprains, and related these improvements to improved proprioception. A limitation to their study was that no measures of proprioception were taken in order to directly conclude that the balance board training program caused any improvements or changes in the participant's proprioceptive ability (Verhagen, 2004). Similarly a study performed by Mattacola & Lloyd (1997) assessed balance control using a 6 week strength and proprioceptive training program (single leg stance on a kinesthetic ankle board-flat platform atop a rolling cylinder used to enhance proprioception) (Mattacola and Lloyd, 1997). The results showed improvements in dynamic balance for all participants. However, again no direct measure of proprioception was assessed. The discrepancy between the impact of balance training and proprioception is common in the literature (Mattacola & Lloyd, 1997; Verhagen, 2004), leaving a need for the exact relationship between balance and proprioception to be defined.

2.6.4 Proprioceptive Training

In order for the results of a balance training program to show proof of improved proprioception, pre and post measures of proprioception must be examined, as well as a thorough understanding of the effects of ageing on proprioception. A study performed by

Westlake and colleagues, in 2007 compared various proprioceptive testing measures, postural sway and a functional task performance (walking) of 46 participants (Westlake et al, 2007). Westlake and colleagues used TPM, JPS, and velocity discrimination as measurements of ankle proprioception and these results were compared to mean velocity and total length of the centre of pressure path during a two foot quiet stance (Westlake, 2007). Each participant was also evaluated on their gait speed and time taken on a stair climbing test. Results of this study revealed a decline in ankle proprioception, indicating changes in our proprioceptive abilities as we age. Westlake and colleagues suggested that the inclusion of a precise exercise program may diminish or decrease this age related change in proprioception (Westlake et al., 2007).

A second study performed by Westlake et al. (2007) recently looked at the link between balance training and proprioception. They examined the effects of an 8-week balance training protocol on three proprioceptive measures of the ankle (TPM, JPS, and velocity sense) in an older population (60-70 years old). Results of this study showed short term improvements in velocity sense that later diminished, and no change in TPM or JPS for the older adult population. The study does not indicate any improvements in proprioception related to the balance training program prescribed (Westlake, 2007). Bullock-Saxton et al. (2006) indicated that there are no age related differences between measures of active JPS testing during weight bearing stance. This suggests that the results seen by Westlake et al. (2007) should be replicable in adults of all ages (Bullock-Saxton, 2006).

3. Research Rationale and Purpose

Proprioception is an important contributor in the maintenance of postural stability, and it's involvement in balance has generated interest in the trainability of proprioception, with the potential of developing heightened responses to unstable perturbations. However, research supporting the positive effects of balance training on proprioception remains unfound. Prior to discovering the trainability of this sensory system, a greater understanding of the proprioceptive system is required. The knowledge of the relationship that proprioception has on balance is essential. If proprioception does play a direct role on balance control, does this result suggest that if one has good balance, they must also have good proprioception?

4. Hypothesis

The hypothesis of this randomized controlled study were that participants, who showed a smaller postural sway while standing on their dominant single leg (low horizontal force deviation, and CoP variables) would show a lower TPM value (degrees of movement to detection) indicating a potential linear positive relationship between single leg standing balance and proprioception using the TPM as a measure for proprioception.

5. Methods

5.1 Study Participants and Design

5.1.1 Participants

Thirty healthy participants between the ages of 20 and 32 years of age (mean age 25 +/- 4 years with 15 males and 15 females) from the University of British Columbia community were recruited for this study. Participants were excluded from this study based on the following exclusion criteria: (1) current or chronic lower extremity joint disorders, (2) indication of a balance related disorder (vertigo, stroke etc.) and (3) Exclusion of participant with a history of ankle sprains. Participants who require prescription glasses were asked to use corrective lenses throughout the duration of the experiment.

Potential participants were recruited using an internal participant recruitment web posting for UBC students. The study was approved by the University of British Columbia Behavioral Research Ethics Board (see Appendix C). Informed consent was signed and obtained from all participants prior to the study (see Appendix B).The experiment took approximately one hour to complete and participants were instructed not to perform any rigorous lower limb physical activities 24 hours prior to testing in order to avoid fatigue or extreme muscle inflammation.

5.1.2 Experimental Setup

Each participant's dominant ankle was tested for threshold to passive movement (TPM) during a whole body standing braced ankle proprioceptive task which assessed individual's levels of proprioception. The dominancy of the ankle was determined according to the leg used most commonly in sports (ie. kicking a ball). Results of the TPM test were compared to a single leg balance task. The single leg balance task was assessed pre and post test to the TPM trials.

Silver-Silver Chloride electromyography recording electrodes were placed on the primary inverter of the foot (tibialis anterior (mid belly)) and an evertor of the foot (peroneus brevis muscle (mid belly)), and a ground electrode on the lateral malleolus of the testing limb. Muscle activity was recorded during trials to assess the levels of muscle activity within the lower limb during the threshold tests. Minimal activity was required to be present prior to initiation of a new trial. EMG was monitored online during the trials, and the initiation of each TPM trial was controlled by the experimenter to ensure muscle activity was minimal prior to initiation.

Threshold to Passive Movement Sense (TPM) - Participants were braced to a vertical bracing board mounted on a lifting platform allowing for height adjustment in the bracing board (see figure 2). The participant's dominant foot was placed on a rotating foot plate (figure 3 below). The custom built rotating platform contains a rotating swing powered by a servomotor, and triggered for movement using a computer system and Spike 2 software. The bracing enabled each participant's ankle to remain body weight loaded, while maintaining upright posture, localizing movement to the ankle joint in the medio-lateral plane, and eliminating movements at the head. Each participant underwent one randomized 35 trial block which was composed of 15 inversion trials, 15 eversion trials which were all presented at 0.25 degrees/sec and 5 sham trials during which the platform did not move.

Figure 2 Set Up for Participants

Figure 3 Foot Plate with Servomotor

Participants were braced to a bracing board at the hips and shoulders, isolating movement from the tilting platform to the ankle joint but at the same time maintaining a loaded ankle. The participant's dominant foot was placed on a foot plate powered by a servomotor that inverted or everted the ankle at a rate of 0.25 degrees per second and vision was limited through use of vision limiting goggles. Participants were asked to trigger one of two finger switches indicating either an inversion or eversion movement detection, once a movement at the ankle was detected and the participant also detected the direction of the movement. To prevent guessed responses from the participants sham trials ranging from twenty to thirty seconds were included throughout each block of trials. The sham trials consisted of the motor of the tilting platform remaining on but no movement of the platform occurred.

Single Leg Standing Balance: Each participant underwent three single leg stance trials using their dominant leg. Participant's visions was partially occluded with goggles that removed all vision below the eye level and were asked to maintain three 60 second single leg stance trials on a force plate with one minute of rest between trials to minimize fatigue. The single leg stance test duration was chosen based on conclusions made by Carpenter et al. (2001) who showed that when sampling CoP during single leg stance for periods equal to or greater than 60 seconds, there is an increase in the reliability of the center of pressure measures, and low frequency components are captured completely (Carpenter et al., 2001). Participants were instructed to stand as still as possible with their hands by their side and vision limited from the placement of the goggles. Maximum displacement measured in millimeters of each participant's CoP in the medial lateral sway (x axis) and the anterior posterior (y axis) direction and RMS of velocity was calculated using their horizontal force and CoP data collected on the force plate.

5.2 Data Analysis

To ensure no learning effect or potential performance effect had taken place throughout the TPM trials for each participant, trials one to fifteen for inversion and eversion were plotted and visually analyzed. For each participant's ankle inversion and eversion TPM trials were plotted against the degrees to detection for each TPM trial in order to assess for any improvements in performance.

The six single leg stance trials were separated with three trials presented pre test to the TPM trials and three post to the TPM for the purpose of assessing any potential fatigue. Fatigue will was assessed using a t-test pre to post to assess for a potential significant difference. RMS velocity and RMS of the horizontal forces of the pre-test trials and post test trials were compared using an T-test to determine if the two sample means differed from each other ($p<0.05$).

5.2.1 Correlation

RMS of the velocity, horizontal force and the maximal displacement of each participants single leg stance (pre & post test), and TPM measure at 0.25 degrees were used to investigate the relationship between single leg stance and TPM. The force plate and TPM data were collected and analyzed using SPIKE2 software. Force plate (medial/lateral/anterior/posterior) data was analyzed using the RMS of the velocity of postural sway. The total displacement in the medial-lateral (ML) and anterior-posterior (A-P) direction that took place over the 60sec single leg balance task, as well as the horizontal force (Fx) was calculated. Corresponding variables (RMS velocity, COPx, COPy, maximal displacement (ML and AP), and horizontal and vertical forces (Fx and Fy) were pooled and a correlation (*r*) coefficient value was calculated from each of the variables of the single leg balance task compared to degrees calculated for TMP for all participants in either the inversion or eversion direction.

$$r = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{N\sum X^{2} - (\sum X)^{2}}\sqrt{N\sum Y^{2} - (\sum X)^{2}}}$$

The *r* value revealed if there was a positive or negative linear relationship between single leg balance and the loaded ankle TPM eversion and inversion tests. The meaningfulness of the correlation coefficient *r* was determined by the coefficient of determination r^2 value, which revealed the strength of the relationship.

6. Results

A mean, median and standard deviation was calculated for the CoP (x and y), maximal displacement (x and y), RMS velocity of the CoP, anterior-posterior and medial-lateral forces, as well as the number of step downs that occurred from the single leg standing data and analyzed against the TPM value in degrees to detection for each participant. The above variables are reported in the below table.

Table 1 TPM and Force Plate Data

Variable	Mean	Median	Standard Deviation
TPM (degrees) Inversion	1.585	1.522	0.702
TPM (degrees) Eversion	1.532	1.487	0.615
Fx (M-L) (N)	0.269	0.270	0.113
Fy (A-P) (N)	0.065	0.062	0.012
RMS Velocity mm/s (Non-Directional)	0.052	0.024	0.151
COPx (mm)	3.827	0.209	5.166
COPy (mm)	-0.191	0.209	1.833
Total X Displacement (mm)	30.939	13.176	34.751
Total Y Displacement (mm)	38.566	12.703	73.881
Step Downs	0.610	0	1.365

The results above show a greater mean horizontal force and COP during the single leg stance in the medial-lateral (M-L) directions compared to movements seen in the anterior posterior (A-P) direction. However the mean displacement seen in the M-L direction was slightly less than the A-P direction, with there being a large standard deviation in Y displacement variable indicating a large amount of variability between the responses seen in the participants used.

Threshold to Passive Movement

Threshold to passive movement was measured in order to assess proprioception in the ankle joint in the inversion and eversion directions. The measure being assessed is in degrees to detection of the inversion or eversion movement. Each participant was exposed to 15 inversion and 15 eversion trials, and correct and incorrect responses were recorded. The repetitive nature of the task left participants susceptible to fatigue or a learning effect. For these reasons learning effect, fatigue and errors were all assessed.

6.1 Range

The inversion and eversion results were analyzed separately for response rate and errors. In the eversion direction TPM response data fell between 0.302 degrees and 2.763 degrees, with the largest value in degrees for a correct response being 2.948 and the fastest being 0.399, showing that the results fall slightly out of the normal distrubution curve which is indicated by 95% of the responses falling within two standard deviations above and below the mean (Figure 4). A Kolmogorov-Smirnov test revealed a statistical value of 0.051 with a p value of 0.014 showing that the distribution seen for the eversion TPM responses were statistically different from a normal distribution. The skewness of the distribution of the eversion TPM (degrees) responses was calculated to be 0.220.

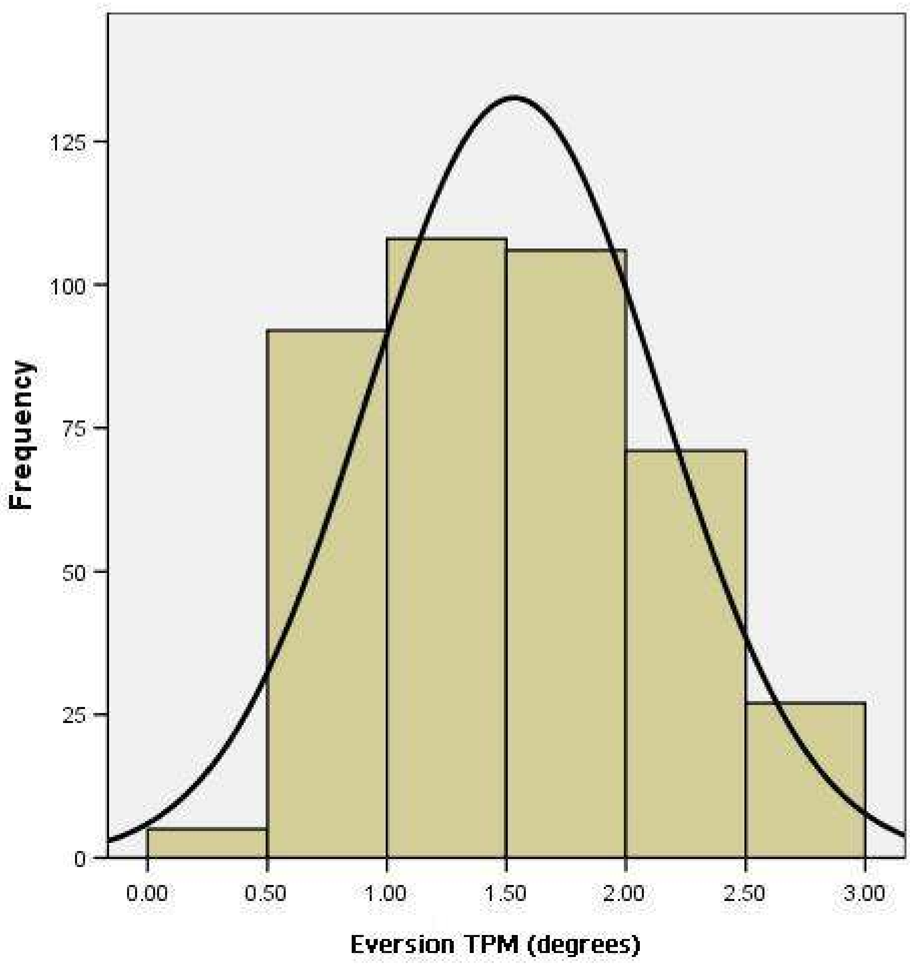

Figure 4 Eversion TPM Range of Responses

The eversion TPM range of responses is depicted above, the mean response at 1.532 degrees with 95% of the results falling between the range of 0.302 and 2.763 degrees.. The line represents a normal distribution curve.

In the inversion direction 95% (mean +/- 2 SD) of the TPM response data fell between 0.197 degrees and 2.928 degrees (Figure 5), with the slowest value for a correct response being 2.9805 degrees and the fastest being 0.243 degrees, showing that the results fall slightly out of the normal curve, with the distribution having a having a slight positive skew (skew to the right skewness=0.275). A Kolmogorov-Smirnov test revealed a statistical value of 0.075 with a p value of 0.000 showing that the distrubution seen for the inversion TPM responses were statistically different from a normal distribution.

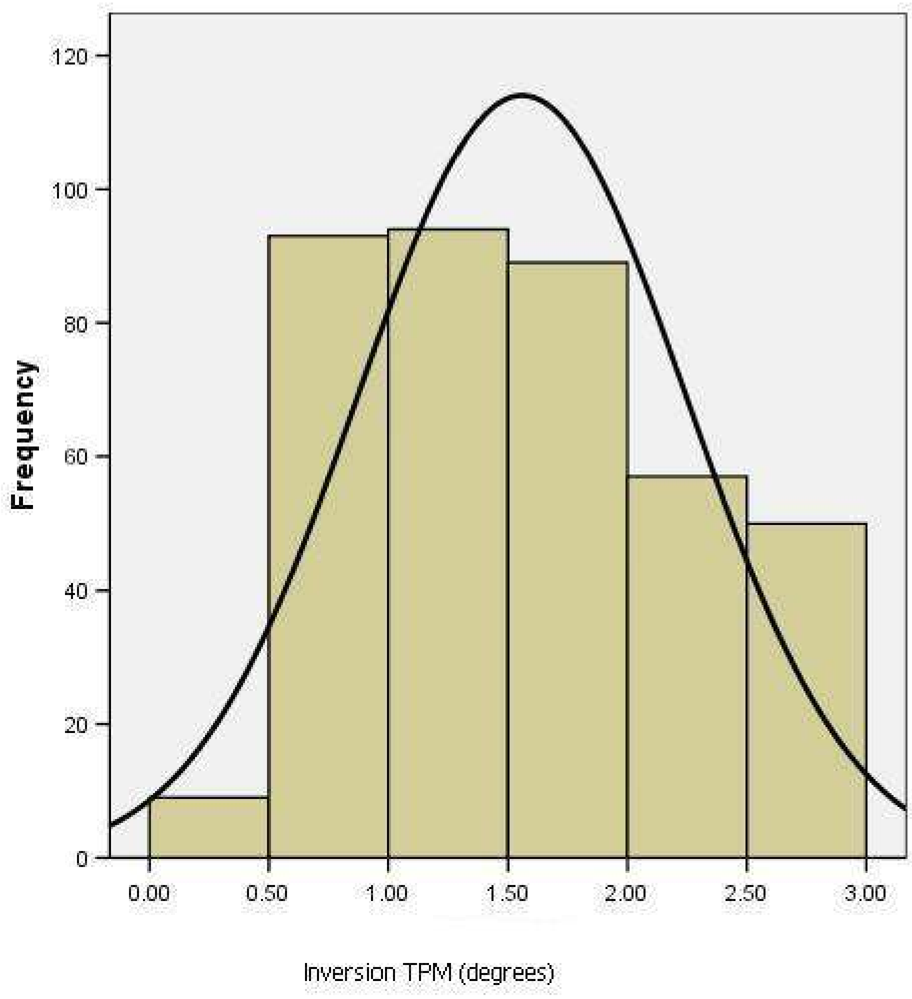

Figure 5 Inversion TPM Response Range

The inversion TPM range of responses is depicted above, the mean response at 1.585 degrees with 95% of the results falling between the range of 0.197 and 2.928 degrees. The line represents a normal distribution curve.

6.2 Learning Effect

With the repetitive nature of the testing procedure, the data was visually analyzed for a learning effect. A learning effect would be indicated by a gradual decrease in the degree to detection of the TPM inversion or eversion trials, or otherwise an improvement in performance. An average TPM (degrees) value for all participants was plotted both for the inversion and eversion trials in order of appearance and visually analyzed for a trend that resembled a decrease in the degrees of movement to detection throughout the testing period. No trend showing a decrease in the TPM responses (degrees) was seen indicating that no learning effect took place within the trial blocks.

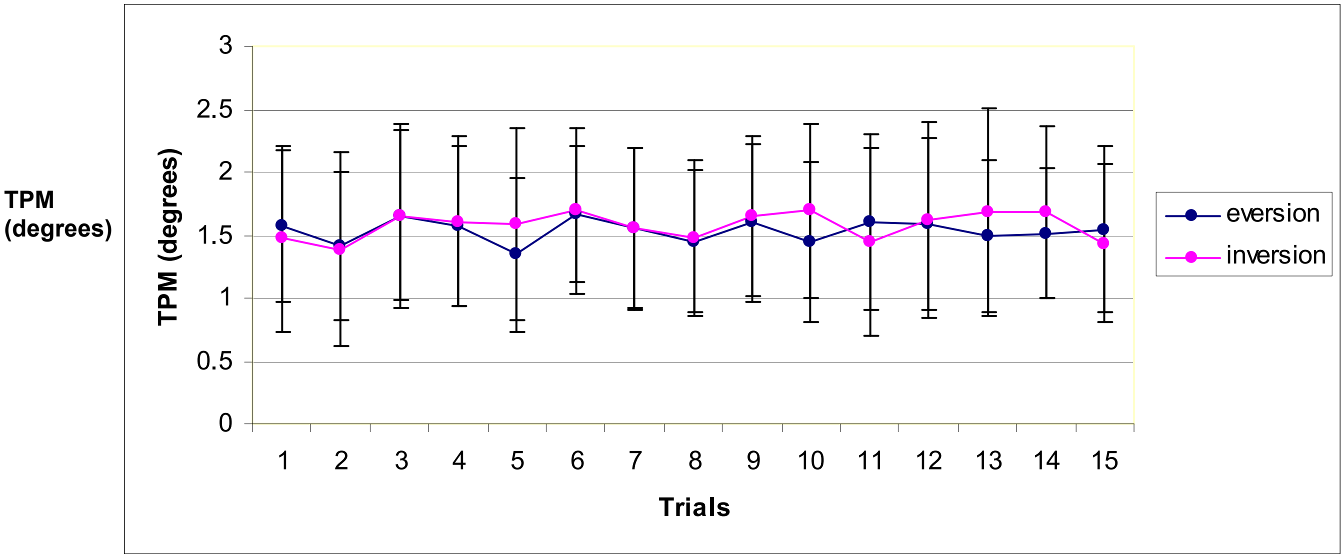

Figure 6 TPM Trial Learning Effect

No upward or downward trend is seen in the above graph which indicates the absence of a learning effect. The results of the responses show increases and decreases in the response rate for both inversion and eversion between trials.

6.3 Fatigue Effect

Pre TPM trials and post TPM trials data were taken during the single leg standing task (CoPx, CoPy, RMS Velocity, X maximal displacement, Y maximal displacement, Fy and Fx) in order to assess for any potential effect of fatigue during the TPM trials. Based on a t-test using the data of all thirty participants comparing the pre and post test data for each variable above, no significant ($p>0.05$) differences were seen, indicating that no fatigue effect took place throughout the TPM trials.

6.4 Errors

Of a total of 900 TPM responses collected from the 30 participants tested, there were 83 errors (9.2% of the trials), providing an error ratio of 83:817 overall, with 6.67% of the responses in the eversion direction containing errors and and 11.78% for the inversion TPM results. The low number of incorrect responses indicates that the instructions provided to the participants were very clear. Incorrect results were not used in the calculations of the earlier stated means, medians and standard deviations as most incorrect responses were due to a delayed response, and later participants verbalized that they were either not paying attention on that trial, or were not absolutely positive of the direction of the movement providing a delay in the response.

88% of the inversion trials and 93.33% of the eversion trials resulted in correct responses, however 11.78% of the inversion trials, and 6.67% of the eversion trials were answered incorrectly. Errors seen throughout the TPM trials were categorized by either being an incorrect response (IR), a late response (LR) (responses taking place after the movement of the plate ended) or a no response (NR). Errors were seen both during the sham trials (no plate movement) as well seen to occur throughout the inversion or eversion movement trials. There were a total of 83 (9.2%) errors during the TPM trials (inversion and eversion) combined with 63.86% of these errors taking place during the inversion trials and 36.14% during the eversion trials.

The results indicated that a greater portion of the errors (63.86%) was attributed from the inversion TPM trials with 49.06% of these errors being due to LR, 43.40% NR and 7.55% IR of the inversion trial errors. Errors detected during the eversion trials made up 36.14% of the total errors that took place during the testing period for the 30 participants. During the eversion trials the majority of errors (57%) were made due to LR, and 36.67% due to NR. The IR seen during the eversion trials made up 6.67% of the errors.

6.5 Single Leg Standing Trials

Thirty participants underwent six single leg standing trials on their dominant limb. Three trials took place prior to the TPM testing and three trials post TPM testing. The separation of trials allowed for assessment as seen above for fatigue potentially caused by the TPM testing procedures. Participants were required to perform six 60 second single leg standing trials, and were instructed to maintain as still as possible throughout the testing period, however instances of loss of balance did occur throughout the trials. Due to the occurrence of what is defined in this experiment as a “step down” which is when a participant’s steps down with the non-dominant limb onto the force plate, this data must be analyzed.

6.6 Step Downs

The definition of a step down is when a participant stepped down on the force plate during their single leg standing trials with the non standing limb, which was represented by a large deviation in the force plate data. Eighteen of thirty participants in this study had at least one or more step downs during the single legs standing trials. The next calculations are meant to determine if the event of a step down is indicative of the participant’s standard deviation and or median TPM results during the inversion and eversion TPM trials.

A logistical regression suggests that the probability of an event (step down) may be affected by one or more explanatory variables (TPM result during the inversion and eversion proprioceptive tests). The results of the amount of step downs throughout trials is represented by either a 0 or a 1 (0= no step down) 1= step down). A logistical regression is useful in describing the relationship between a risk factor (step downs) and an outcome such as ones TPM results. When graphed a significant logistic regression would resemble a sigmoidal curve or s- shape indicating a probability that two variables are related.

Logistical Regression of Step Downs and Inversion & Eversion TPM Results

The logistical regression performed using the step down (=1) and no step down (=0) SD and median TPM data for the inversion trials showed no significance for either variable combination which is indicated by the p value of 0.968 and 0.847 (inversion SD and median vs. No step downs) and 0.918 and 0.843 p value for the inversion SD and median value vs. step downs.

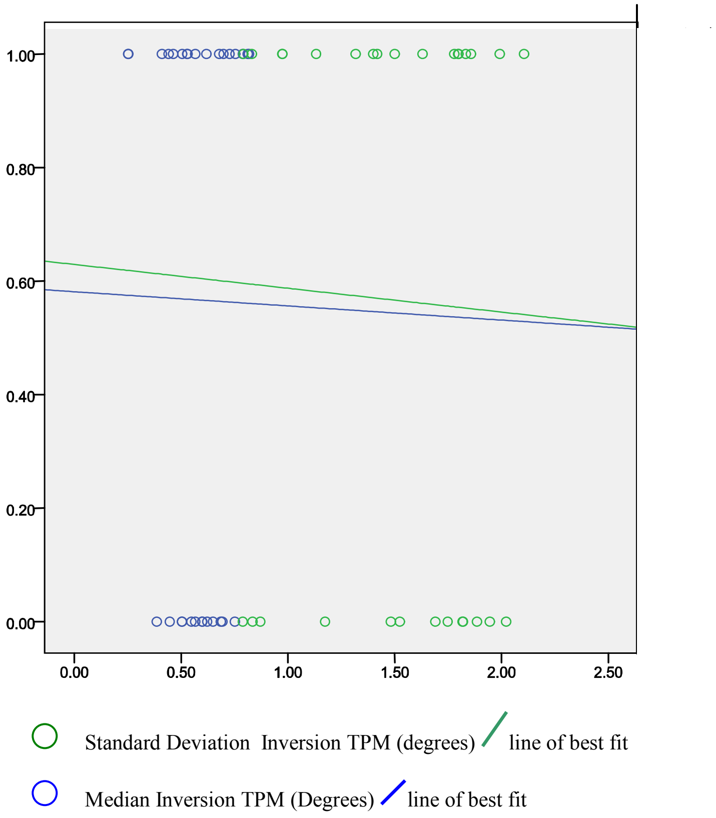

Figure Inversion Logistical Regression: TPM (SD & Mean) & Step Down Data

(Step down= 1, No Step down=0)

The logistical regression using the eversion SD and Median TPM data indicate that there is a potential relationship between one's eversion SD during the TPM test and whether or not the participant takes any step downs during the single leg standing task. This is indicated by the p values of 0.054 (eversion SD vs. No step downs) and the 0.072 p value (value approaching significance) for the eversion SD vs. Step downs. However no significant value was found when calculating the relationship between the eversion median value and step downs.

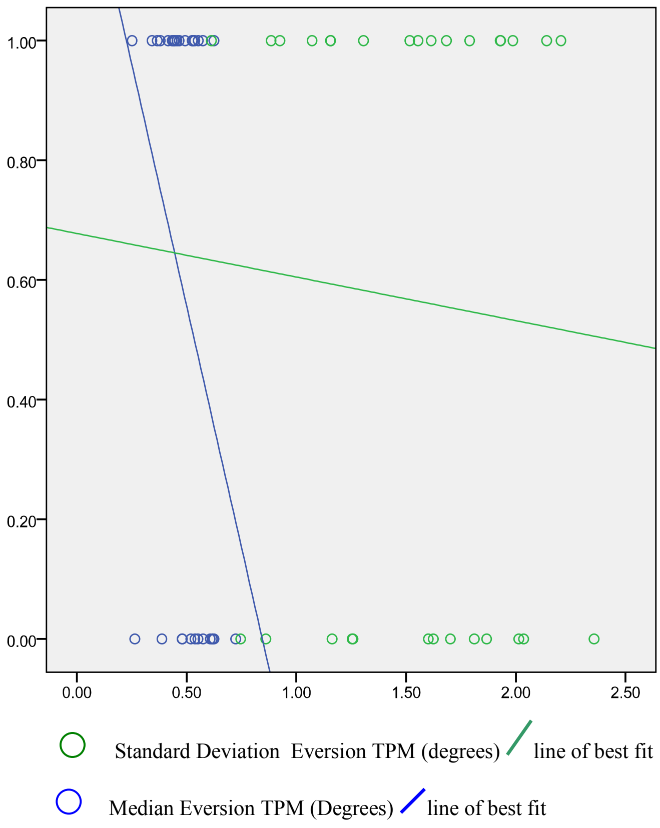

Figure 7 Eversion Logistical Regression: Eversion TPM (SD & Mean) & Step Down Data

(Step down= 1, No Step down=0)

6.7 Correlations

Using the median and standard deviation values for each of the single leg standing variables calculated a correlation was run against the mean TPM (degrees) results in the inversion and eversion direction of the thirty participants. The results below indicate the correlation results of the SD and Median value for TPM (degrees to detection) inversion & eversion results compared to Total Y displacement, X displacement, COPx, COPy, RMS Velocity, Fx (Horizontal Force) and Fy (Vertical Force) as well as step downs.

Table 2 Correlation Mean TPM and Force Plate Data

	R-Value			
	Inversion	Eversion	Relationship	Significance
X Displacement (mm)	0.232971	0.295834	Positive	Not Sig.
Y Displacement (mm)	0.227068	0.275809	Positive	Not Sig.
COPx (mm)	-0.24843	-0.04035	Week negative	Not Sig.
COPy (mm)	0.31748	0.148668	Positive	Not Sig.
RMS Velocity (mm/s)	-0.15256	0.012837	Weak positive	Not Sig.
Ap (Fy) (N)	0.246415	0.260956	Positive	Not Sig.
ML(Fx) (N)	0.038977	-0.16575	Negative	Not Sig.
Step Downs	0.14223	0.155712	Positive	Not Sig.

Table 3 Correlation Standard Deviations and Force Plate Data

	R- Value			
	Inversion	Eversion	Relationship	Significance
X Displacement (mm)	0.211204	0.150514	Positive	Not Sig.
Y Displacement (mm)	0.322039	0.206206	Positive	Not Sig.
COPx (mm)	-0.07086	0.146462	Positive	Not Sig.
COPy (mm)	-0.07308	0.141569	Positive	Not Sig.
RMS Velocity (mm/s)	0.025999	0.017944	Weak positive	Not Sig.
Ap (Fy) (N)	0.317599	0.121937	Positive	Not Sig.
ML(Fx) (N)	-0.3477	0.174858	Positive	Not Sig.
Step Downs	0.105793	0.138355	Positive	Not Sig.

95% confidence interval for the correlation coefficient= n-1= 0.5139 represented by the r value. The r^2 value interprets the meaningfulness of the correlation coefficient, indicating the portion of the total variance in the measure.

Using the correlation coefficient of 0.5139 which is calculated based on 30 participants (n-1) the correlation coefficients calculated from the above standard deviation and median data against the TPM inversion and eversion results in degrees, resulted in non significant values.

7. Discussion and Conclusions

7.1 Discussion

The present study aimed at investigating the relationship between single leg standing balance and ankle proprioception. Thirty healthy participants were exposed to thirty TPM trials (15 inversion and 15 eversion), and six single leg standing trials. TPM responses were measured at 0.25 degrees/second in the inversion and eversion direction in thirty participants. Pre and Post to the TPM measures, participants underwent three single leg standing trials on a force plate, with the aim of investigating the relationship between single leg standing balance and ankle proprioception in the inversion and eversion directions.

Results of the experiment yielded no significance in the correlations of the TPM inversion and eversion results versus the variables collected from the single leg standing data on a force plate. The results of this experiment failed to reject the null hypothesis.

7.1.1 Threshold to Passive Movement Detection (TPM)

The TPM testing protocol is dependent on three critical factors; sensory afferent information evoked from the joint movement, the time taken for central processing and the decision criteria by the participants to indicate whether the movement was in the inversion or eversion direction. There are two commonly used techniques when assessing ankle proprioception; active or passive joint position sense, and threshold to passive movement. A braced standing weight bearing position was used to test the TPM protocol in the assessment of ankle proprioception. There is evidence that when testing using a TPM protocol that a weight bearing position is a more accurate measure than non-weight bearing in the assessment of fall risks and postural control (Bullock-Saxton et al., 2001).

The nature of the TPM testing protocol used in this experiment resulted in some participants commenting on fatigue or stiffness created in the joints, however results seen from the pre- and post single leg standing balance data did not show that fatigue was a factor in the results. As well the repetitive nature of the measurement protocol did not indicate any presence of a learning effect (figure 6) during the TPM trials, along with the low ratio of errors seen in the data (inversion 53:397 and eversion 30:420) all provide support for the methodologies used.

7.1.2 Single Leg Standing Balance

Postural Control or balance is a product of the central nervous system, the musculoskeletal system and the sensory system. The assessment of postural control has commonly been accomplished via participants standing on one limb on a force plate in a modified version of the Rhomberg Position; hands by their side, with eyes open looking forward. The use of force plate data in recent studies for the assessment of balance during unipedal/single leg stance has shown to be an appropriate indicator of functional ankle instability (Hertel et al., 2001; Hertel & Olmstead, 2007; Ross et al., 2007). Results of these studies have shown; that the time to boundary measure of CoP on a force plate was indicative for chronic ankle stability (Hertel & Olmstead, 2007), as was CoP displacement length and RMS velocity (Hertel et al., 2001), and within an older population displacement of CoP served as a measure for the assessment of fall risk (Pajala et al., 2008). The relationship of force plate data and balance assessment was reported by Karlsson and Frykberg in 2000 that performed a correlation study on the force plate measures and the assessment of balance. Results found that the following variables had a significant correlation indicating a relationship between some force plate variables and balance; standard deviation of the horizontal forces, and standard deviation of CoP (Karlsson & Frykberg, 2000). All studies mentioned provide support for assessing balance using force plate data for the assessment of ankle stability as well as one's risk of falling meant to be an indicator of postural control, however not specific to single leg stance protocols. The results seen in the current study showed a variation of single leg standing abilities within the population that was tested. With higher deviations in the Fx and CoPx showing that during single leg standing the majority of movement takes place in the M-L direction.

7.1.3 Proprioception and the Relationship with Single Leg Standing Balance

In order to maintain stability we are dependent on the ability of our sensory system to extract inputs that relate to the orientation of the body, this information then is integrated within the central nervous system and as a result the appropriate motor responses are activated, with proprioception being an essential component to this equation. Proprioception provides information relating to the sense of movement (kinesthesia) and the position of joints (joint position sense). Proprioception is often used to describe many of the physiological processes within the sensorimotor system including joint position sense, kinesthesia, balance, reflex, muscle activation, and even to the description of locomotion.

Literature has proven that human balance is dependent on the constant flood of sensory information to our CNS to allow for appropriate reflexive and motor responses to occur. The sensory information is key to the maintenance of stability, however the results seen using the current testing procedures failed to identify this relationship. The results seen from the correlation data assessing the relationship between single leg standing data on a force plate and ankle proprioception measured by means of TPM in the inversion and eversion direction failed to reject the null hypothesis. However, when a logistical regression was done on the occurrence of a step down during the single leg standing data and the TPM data it was found that when the participants did not step down (p= 0.05) it was significantly related to their eversion SD TPM trials. This significance indicates that there is a relationship between one's performance on a force plate indicated by their ability to maintain balance on one leg (without stepping down) and their ability to detect slow small movements in the eversion direction of the ankle joint.

The study performed by Westlake and Colleagues in 2007 is one of the studies to date that is the closest into investigating this relationship of ankle proprioception and balance by means of the assessment of ankle proprioception using TPM, JPS and velocity discrimination and an eight week balance training protocol (Westlake et al., 2007). No long term improvements in the proprioceptive measures were seen as a result of the eight weeks of training (Westlake et al., 2007). Based on the reviewed literature and the results seen in this experiment the relationship between single leg balance and ankle proprioception requires further investigation.

7.2 Limitations

The results found following the correlation analysis for this study were not what was expected when initiating this experiment, thus it is important to mention the limitations in the testing procedures for this study. First, proprioception at the ankle joint was tested only using one measure and in only one plane (medial-lateral), and in the dominant limb. One recommended methodological change would be to use a second measure for this assessment as well as to assess the TPM detection rate in the AP plane for comparison in both the dominant and non-dominant limb. The results of the TPM data are dependent on the conscious perception of signals from sensory receptors. The quantity of proprioceptive input required for conscious perception versus the amount required for motor control is unknown, such that multiple parameters of proprioception should be assessed.

There is support in the literature for the use of CoP as a measure of postural control, fall risk assessment and functional ankle instability, but there translation to ankle proprioception remains unknown (Hertel et al., 2001; Hertel & Olmstead, 2007; Ross et al., 2007). Second, during the assessment of TPM bracing techniques, EMG monitoring and slight vision occlusion were used to control the testing environment however cutaneous inputs on the foot may have aided in the detection times of the TPM trials. Although cutaneous afferents were not directly minimized they were existent in all participants, thus constant within.

7.3 Conclusions

The complete role and contribution of proprioceptive information to standing balance are not fully understood. The initial questions of the relationship between balance and proprioception is left unclear based on the results of this study. Evidence does suggest that balance and proprioception has been linked together (Ribot et al., 1986; Clark et al.,1993; Ashton-Miller et al., 2001; Verhagen et al., 2004), however the methods chosen for this experiment failed to reveal a relationship outside of the occurrence of step downs and eversion SD TPM. A follow up experiment is necessary to further investigate this relationship. To gain some understanding of the impact that proprioception might have on balance control, we need to establish the relationship between these two variables. A better understanding of the contributions that proprioceptive inputs have on balance control will allow for the development of diagnostic tools to assess neurological deficits (e.g., deafferentation, vestibular loss) that affect balance.

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Appendix- A

A-1 The Ankle Joint

The ankle is a joint that is formed where the foot and the lower leg meet. The ankle joint is referred to as the talocrural joint and is a synovial hinge joint that connects the distal end of the tibia and fibula in the lower limb with the proximal end of the talus bone in the foot (Rieman, 2004). The articulation between the tibia and talus is subject to the majority of the weight bearing (Rieman, 2004). The ankle joint and the surrounding ligaments represent a complex mechanical structure that is dependent on ligament integrity (Rieman, 2004). The ankle complex comprises three articulations: the talocrural joint, the subtalar joint and the distal tibiofibular syndesmosis (Rieman, 2004). These 3 joints work together to allow coordinated movements of the rear foot.

Rear foot motion is defined as being in the cardinal planes and includes motions such as plantar flexion/dorsi flexion, saggital plane, inversion/eversion, frontal plane, transverse plane, internal/external rotation (Arnold, 2006). Rear foot motion does not move in isolation in the individual planes rather it is coordinated movements of the three joints that allows the foot to move as a unit about an axis of rotation (Arnold, 2006). The main joint of interest when referring to single leg balance is the joint responsible for inversion and eversion ankle movement: the subtalar joint.

The subtalar joint is formed by articulations between the posterior facet of the talus and the superior/posterior facet of the calcaneous (Arnold, 2006). The subtalar joint allows for movements at the ankle: supination/pronation, internal and external rotation. The subtalar joint has an anterior and a posterior component (Arnold, 2006). The anterior subtalar component, also known as the talocalcaneonavicular joint, is formed from the head of the talus, the anterior superior facets, the sustaentaculum tali of the calcaneous and the concave proximal surface of the tarsal navicular (Arnold, 2006). The joint articulation is similar to a ball and socket joint with the talar head being the ball and the anterior calcaneal and proximal navicular surfaces forming the socket. The anterior and posterior joints have separate joint capsules. The anterior joint lies further medially and has a higher centre of rotation than the posterior joint, however the two joints do share a common axis of rotation (Arnold, 2006).

The subtalar joint which allows for inversion or eversion has an oblique axis of rotation, which averages a 42 degree upward tilt in the saggital plane and 16-23 degree medial angulations in the transverse plane from the perpendicular axis of the foot (Arnold, 2006). Gilsing et al. (1995) found the axis of rotation for inversion and eversion of the foot at the subtalar joint should be set to be co-linear with the cradle of rotation (Gillsing, 1995). This axis of rotation should be the one used for the focus of proprioception role in the prevention of lateral falls in the single limb support phase of gait.

Ankle stability is important in whole body function, movement and for injury prevention. Vernhagen et al. (2004) maintain that ankle sprains are the most common injury in a variety of sports and through experimentation they found that by incorporating a balance training paradigm it significantly reduced the reoccurrence of ankle sprains among athletes (Verhagen, 2004). Ankle injuries are the most common injury across numerous sports and are often at a higher risk for re-occurrence due to the function of the joint. Ankle stability has been suggested to be improved through proprioception or balance training, and could also be a tool for the prevention of ankle sprains (Verhagen, 2004).

A-2 Receptor Contribution to Movement and Balance

The removal of sensory feedback to the CNS can impair motor function. This is evidenced in tasks requiring dexterity and context dependent control (i.e., typing, walking on a balance beam). Balance is dependent of the receipt of information from the peripheral receptors, as the loss of proprioception has been shown to cause detrimental effects on the neuromuscular control of the joints (Refshauge et al., 1996). The role of afferent receptors and their contributions to sensory perception have been outlined in previous sections; however the contribution of these receptors in locomotion has yet to be stated. Everyday movement causes constant input from the sensory receptors providing the body with the location of the limbs in space, and when needed the responses to perturbations via spinal reflexes or automatic pre-programmed responses. Proprioceptive, visual and vestibular information collected work as both a feedforward or feedback mechanism.

The CNS functions to integrate afferent signals and regulate motor commands controlling voluntary muscle activation for performance of complex motor skills along with involuntary motor responses that contribute to joint stability. Coordinated movements such as locomotion, and balance are dependent on feedback from peripheral receptors (joint, cutaneous, and muscle receptors) in order to modulate movement. The motor neuron pools of afferent inputs and efferent outputs are both highly adaptable, allowing for versatile and coordinated movements. The peripheral afferent information influences the modulation of ongoing movement sequences to maintain spatial coordination in the presence of the ever changing environment.

The neuromuscular control of movement consists of unconscious efferent responses to afferent signals. The utilization of proprioceptive information is categorized in one of two ways; feedback and feedforward. Feedback refers to a reactive process traditionally at the spinal level and supraspinal level in response to joint loads providing a conscious appreciation of position and motion that can be used for fine tuning of motor commands for precision of movements at higher brain centres. Feed forward information is a valuable mediator of movement and involves pre-activating the control of muscles in anticipation of loads or subsequent events. This motor control mechanism implies that an internal model is developed by utilizing information from previous exposures to known conditions. Feedback however, is an important contributor to the success of all deliberate movement. Feedback as previously discussed enables for accurate movements, relying on sensory information to adjust the mechanics of the movement (position, muscle fibre recruitment, speed of contraction).

Appendix B- Consent Form

THE UNIVERSITY OF BRITISH COLUMBIA

School of Human
Kinetics
210, War Memorial Gym
6081 University Boulevard
Vancouver, B.C. Canada V6T 1Z1

Informed Consent Form
The Link between Balance and Proprioception

Principal Investigator:
Dr. J. Timothy Inglis, Professor, School of Human Kinetics, Graduate program in Neuroscience, the University of British Columbia. Phone: (604) 822-1626

Co-investigators:

Brynne Elliott BKin. School of Human Kinetics, University of British Columbia,

Dr. Jean-Sébastien Blouin, Professor, School of Human Kinetics, University of British Columbia

Melanie Roskell BASc. School of Human Kinetics, University of British Columbia,

David Nichol BHSc. School of Human Kinetics, University of British Columbia,

Chris Dakin BKHK. School of Human Kinetics, University of British Columbia,

Emergency Telephone Number:
In the event of an emergency, please call Timothy Inglis at anytime, 24 hours a day, 7 days a week.

Subjects Participating in the Study:
You are being invited to participate in this study to help discover the relationship between single leg balance and ankle proprioception. Participants will be excluded from the study due to the following exclusion criteria (1) current or chronic lower extremity joint disorders, (2) indication of a balance related disorders (vertigo, stroke etc.) (3) if they are recovering or have a recent history (within last 4 months) of an ankle sprain, (4) or inability to give an informed consent. All participants who choose to voluntarily participate in this study may withdraw from the experiment at any time.

Purpose:

The purpose of this research project is to assess whether or not there is a correlation between ones proprioceptive abilities in the ankle joint and their single leg balance control in order to discriminate whether or not the two variables are related. Results of this experiment will provide researchers, therapists and trainers with more insight into the trainability of balance and proprioception.

Study Procedures:

If you decide to participate in this study, you will be requested to come to the Human Postural Control Laboratory, Room 32 War Memorial Gym (6081 University Boulevard) at the University of British Columbia. You will be asked to come dressed in a pair of shorts and a T-shirt. The experiment will consist of two experimental procedures.

Experiment 1- Participants will be asked to stand on one foot with their eyes open on a force plate using only their dominant leg. Participants will be asked to remain as still as possible over the duration of a 90-second trial. Participants will be provided sufficient time to rest prior to continuing with addition trials. Participants will be asked to perform this test for a total of six trials, three at the beginning of the experiment and three at the end of the experiment.

Experiment 2- Participants will be braced against a wall using cloth-padded straps, around their hips and shoulders and dominant foot placed on a rotating plate. The non-dominant foot will be placed in a sling placed at a level comfortable for the participant. The bracing will allow for minimal muscle activation in the lower limb while maintaining the ankle load. The participant's will be unable to view the ankle, and will be asked to stare forward at a target placed at eye level. Earplugs will be provided to each participant in order to mask the sound of the motor on the rotating platform. The dominant ankle will be passively internally or externally rotated at one of two speeds. Once the participant has clearly detected the movement has taken place and verified the direction the participant will be asked to press a finger switch indicating this conscious awareness, as well asked to state the direction of the movement.

The duration of this experiment will last no more than 2 hours.

Risks and Advantages:

The results of the study will provide new information on the relationship between single leg balance and ankle proprioception.

The repetitive of the proprioception test may result in fatigue in the ankle and lower limb, leading to possible stiffness in the ankle joint lasting 24-48hours.

Confidentiality:

Any information resulting from this research study will be kept confidential. All documents will be identified only by a code number and kept in a locked filing cabinet in the principal investigators research office. You will not be identified by name in any reports or scientific publications of the completed study. All backup computer files will be kept in a locked filing cabinet, and any data files that reside on the data analysis computer in the Neurophysiology Laboratory (Room 32, War Memorial Gym, UBC), will be number coded and only Dr. Inglis and his research assistants will have password access to these files.

Signing this consent form in no way limits your legal rights against the sponsor, investigators, or anyone else. Your confidentiality will be respected. No information that discloses your identity will be released or published without your specific consent to the disclosure. However, research records and medical records identifying you may be inspected in the presence of the Investigator or his designate by representatives of the Natural Sciences and Engineering Research Council of Canada, Health Canada, and the UBC Research Ethics Board for the purpose of monitoring the research. However, no records, which identify you by name or initials, will be allowed to leave the Investigators' offices.

Contact:

You understand that if you have any questions or desire further information with respect to this study, you may contact Dr. Tim Inglis, Brynne Elliott, Jean-Sébastien Blouin,

If you have any concerns about my treatment or rights as a research participant you may contact the Research Subject Information Line at the University of British Columbia.

Consent:

I understand that my participation in this study is entirely voluntary and that I may refuse to participate or I may withdraw from the study at any time without consequences.

Signing this consent form in no way limits your legal rights against the sponsor, investigators, or anyone else.

I have received a copy of this consent form for my own records.

I understand that I will not be paid for my participation in this study.

I consent to participate in this study by signing in the space provided below.

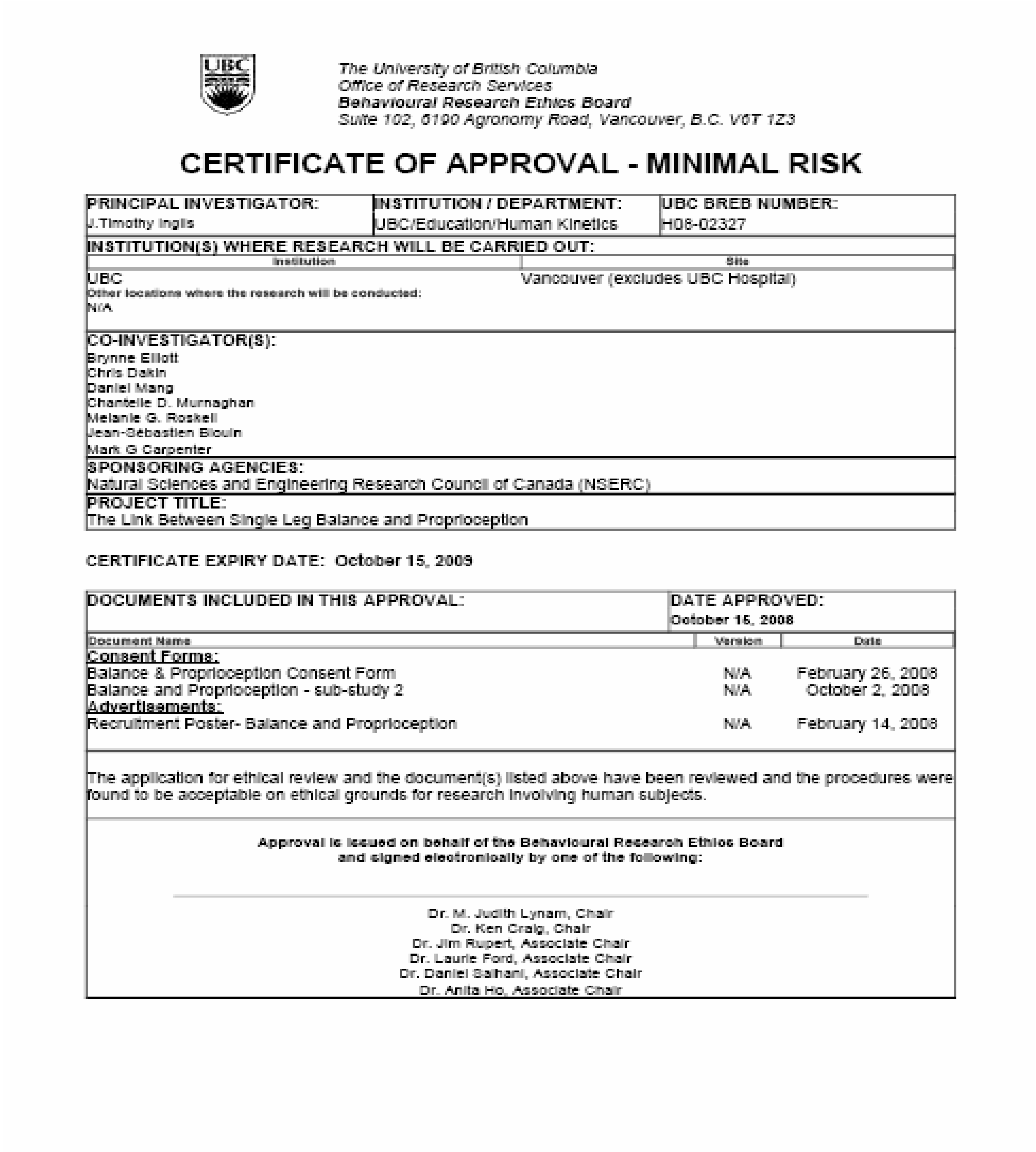
____

Subject's Signature **Printed name of subject** Date

____

Investigator's Signature **Printed name of Principal Investigator** Date

Appendix C- Ethics Certificate of Approval



The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - MINIMAL RISK

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
J.Timothy Inglis	UBC/Education/Human Kinetics	H08-02327

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
N/A

CO-INVESTIGATOR(S):
Brynne Elliott
Chris Dakin
Daniel Mang
Chantelle D. Murnaghan
Melanie G. Roskell
Jean-Sébastien Blouin
Mark G Carpenter

SPONSORING AGENCIES:
Natural Sciences and Engineering Research Council of Canada (NSERC)

PROJECT TITLE:
The Link Between Single Leg Balance and Proprioception

CERTIFICATE EXPIRY DATE: October 15, 2009

DOCUMENTS INCLUDED IN THIS APPROVAL:

DATE APPROVED:
October 15, 2008

Document Name	Version	Date
<u>Consent Forms:</u>		
Balance & Proprioception Consent Form	N/A	February 26, 2008
Balance and Proprioception - sub-study 2	N/A	October 2, 2008
<u>Advertisements:</u>		
Recruitment Poster- Balance and Proprioception	N/A	February 14, 2008

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board
and signed electronically by one of the following:

Dr. M. Judith Lynam, Chair
Dr. Ken Craig, Chair
Dr. Jim Rupert, Associate Chair
Dr. Laurie Ford, Associate Chair
Dr. Daniel Salhani, Associate Chair
Dr. Anita Ho, Associate Chair