

The intra-session and inter-session reliability of centre-of-pressure based  
measures of postural sway within a normal population

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## Declaration

**Name of candidate:** Sarah Teresa Fisher

This Thesis/Dissertation/Research Project entitled **the intra-session and inter-session reliability of centre-of-pressure based measures of postural sway within a normal population** is submitted in partial fulfillment for the requirements for the Unitec degree of Master of Osteopathy.

### CANDIDATE'S DECLARATION

I confirm that:

- This Thesis/Dissertation/Research Project represents my own work;
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.

Research Ethics Committee Approval Number: 2008 - 862

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## ABSTRACT

The objectives of this study were to (1) determine the intra- and inter-session reliability of centre-of-pressure (COP) based measures of postural stability of a normal population and (2) establish a standardised protocol easily repeatable at a tertiary teaching and research facility. Thirty-four subjects (19 females: mean age  $25\pm 4$ ; 15 males: mean age  $29\pm 7$ ; age range 19-42 years) were recruited for this study. COP trajectory was recorded using a Medicauteurs *S-Plate* during three sessions performed over four weeks (week one, two and four). Each trial was comprised of six 75-second tests, three with eyes open and three in eyes closed conditions. The following COP parameters were measured, *Average Speed (medial/lateral & anterior/posterior)*, *Length of COP path*, *Area of COP path* and *Root Mean Square area (RMSa)*. The relative and absolute intra- and inter-session reliability was assessed using intra-class correlation coefficient (ICC) and coefficient of variation (CV). Intra-session reliability proved superior to inter-session reliability in majority of the COP parameters studied, shown by consistently higher ICC values than their inter-session equivalents. *Average Speed (medial/lateral & anterior/posterior)* and *Length of COP path* were the most reliable parameters within and between sessions obtaining Large to Very Large correlation (0.7-0.9) independent of visual input.

In addition this study investigates the relationship between subjective pain intensity and anthropometric characteristics and postural stability in this sample population. This study does not show any meaningful relationship between postural stability and pain, age, height, shoe size, body mass index. However, results suggest that females may have slightly poorer postural stability than males. The information gained through this study maybe a useful foundation for future research in postural stability and the factors that influence it.

*Key Words:* Reliability, Postural Stability, Centre of Pressure, Pain Intensity, Anthropometric Characteristics

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## TABLE OF CONTENTS

Title page	i
Declaration	ii
Abstract	iii
Acknowledgements	iv
Table of contents	v

### SECTION ONE: *Literature Review*

1

	INTRODUCTION	2
1	BODY POSTURE	5
1.2	Functions of Posture	6
2	POSTURAL CONTROL	7
3	THE POSTURAL CONTROL SYSTEM	8
3.1	Mechanisms of the Postural Control System	8
3.1.1	Central Components- Hindbrain reflexes and Postural Control	9
3.1.1.1	Spinal reflexes	9
3.1.1.2	Supra-spinal commands	9
3.1.1.3	Spinal postural reflexes	10
3.1.2	Peripheral Components to Postural Control	11
3.1.2.1	Visual system	11
3.1.2.2	Somatosensory system	11
3.1.2.3	Vestibular system	12
3.1.2.4	Postural reactions	13
3.2	The Corrective Motor Process	14
3.2.1	Ankle and hip strategy models	14
4	POSTURAL SWAY	15
4.1	The Sensitivity of Postural Stability to Multiple Factors	16
4.1.1	The Effect of Pain on Postural Stability	17
4.1.1.1	Neck pain	18
4.1.1.2	Low back pain	19
4.2	Implications of increased postural sway	21
4.2.1	Implications of Postural Sway to Osteopathy	21
5	THE FORCE PLATE AS A MEASUREMENT TOOL FOR POSTURAL STABILITY	23
5.1	Monitoring changes of the centre of pressure (COP)	23
6	RELIABILITY OF POSTURAL SWAY MEASURES	24
6.1	The Number and Length of Trials Necessary to Achieve Reliability	25
6.2	COP Parameters	26
6.3	Influence of Visual Information on Postural Stability and Reliability of Measurement	26
6.4	Intra-session Versus Inter-session Reliability	27
7	The Relevance of Postural Stability Research to Manual Therapy	28
8	REFERENCES	30

## SECTION TWO: *Manuscript*

37

1	<b>INTRODUCTION</b> .....	38
2	<b>METHODS</b> .....	40
	<b>Subjects</b> .....	40
	<b>Stances</b> .....	40
	<b>Procedure</b> .....	41
	<b>Apparatus</b> .....	42
	<b>Data Analysis</b> .....	43
3	<b>RESULTS</b> .....	45
	<b>Intra-session Reliability of COP Parameters</b> .....	45
	<i>Average Speed (Medial/Lateral)</i> .....	45
	<i>Length of COP path and Average Speed (Anterior/Posterior)</i> .....	46
	<i>Area of COP path and Root Mean Square area</i> .....	47
	<b>Inter-session Reliability of COP Parameters</b> .....	48
	<i>Average Speed (M/L &amp; A/P) and Length of COP path</i> .....	48
	<i>Area of COP path and Root Mean Square area</i> .....	48
	<b>The Effect of Visual Input on the Reliability of Measuring Postural Stability</b> .....	49
	<i>The effect of visual input on intra-session reliability</i> .....	50
	<i>The effect of visual input on inter-session reliability</i> .....	50
	<b>The Relationship between Postural Stability and Subjective Pain Intensity</b> .....	50
	<b>The Relationship between Postural Stability and Anthropometric Characteristics</b> ...52	
4	<b>DISCUSSION</b> .....	58
	<b>Intra-session versus Inter-session Reliability</b> .....	59
	<b>Reliability of COP Parameters</b> .....	61
	<b>Influence of Visual Input on Reliability of Measuring Postural Stability</b> .....	64
	<b>Reasoning behind the chosen protocol for this study</b> .....	66
	<b>Data Analysis</b> .....	68
	<b>Postural Stability and Pain</b> .....	70
	<b>Postural Stability and Anthropometric Characteristics</b> .....	71
5	<b>CONCLUSION</b> .....	73
6	<b>REFERENCES</b> .....	74

## SECTION THREE: *Appendices*

81

<i>APPENDIX 1</i> .....	Ethics Resources
<i>APPENDIX 2</i> .....	Health Screening Questionnaire
<i>APPENDIX 3</i> .....	Journal Submission Criteria

**SECTION ONE**  
*Literature Review*

## 1. INTRODUCTION

Standing upright is a task that for many people requires little attention. In order to maintain upright stance, the body is continuously performing a subconscious function of returning the equilibrium of the body's centre of mass vertically above the base of support, comprised of the area of each foot and the ground space between them (Regind, 2003). Postural control refers to the body's ability to maintain equilibrium of the centre of mass by counteracting the constant destabilising forces that challenge it (Harringe, Halvorsen, Renstrom, & Werner, 2008). This requires adequate functioning of a control system, involving a complex interaction of several sensory modalities; visual, vestibular and proprioceptive and specific co-coordinated motor output from many joints (Harringe et al., 2008; Mientjes & Frank, 1999; Radebold, Cholewicki, Polzhofer, & Greene, 2001; Schumann, Redfern, Furman, El-Jaroudi, & Chaparro, 1995). During bipedal stance, the centre of mass oscillates over ones base of support in response to internal and external perturbations (Alexander & La Pier, 1998). This oscillation is termed postural sway. Postural sway is measured through the change in centre of pressure (COP) positioning over time.

Numerous factors and disorders including; injury, aging or pathology (Schumann et al., 1995) can adversely affect postural sway by altering the ability of the body's control system to adapt to changing stimuli, thus increasing both sway and the energy expenditure necessary to maintain upright stance (Alexander & LaPier, 1998). The interruption of balance can bring about a sense of instability, vulnerability particularly for the elderly, as well as predispose falls and further injury (Bauer, Groger, Rupprecht, & Gabmann, 2008; Lafond, Corriveau, Hebert, & Prince, 2004; Lin, Seol, Nussbaum, & Madigan, 2008). Research has shown that individuals experiencing chronic low back or neck pain exhibit compromised postural control shown by increased postural sway when compared to asymptomatic control subjects (della Volpe et al., 2006; Hamaoui, Do, & Bouisset, 2004; Harringe et al., 2008; Mientjes & Frank, 1999; Nies & Sinnott, 1991; Radebold et al., 2001). As lower back and neck pain account for a large proportion of patient complaints seen within manual

therapy, it would suggest that majority of the patients seen by manual therapists have compromised postural control and increased sway. Physical assessments performed by manual therapists typically consist of observation, range of motion testing, strength, function, posture and biomechanical assessment. A rudimentary screen of balance or weight bearing is sometimes included however, not routinely performed by manual therapists despite it being an essential aspect in the performance of daily activities (Alexander & La Pier, 1998).

The two main instruments used to assess postural sway include video footage (Eichman & Shehab, 2001) and force plates (Bauer et al., 2008; Pinsault & Vuillerme, 2009). Some studies utilise the benefits of both devices to gain understanding of different aspects of postural stability such as the effect of dynamic limb movement on sway (Prado, Stroffregan & Duarte, 2007). The use of a force plate is an easy, affordable and specific means to record the trajectory of the COP over a period of time. Force plate recordings are also useful to give an interpretation of the integrity of an individual's postural control system (Bauer et al., 2008; Pinsault & Vuillerme, 2009). For example, whether all the sensory systems involved in postural control are functioning adequately. While the force plate has the potential to be a reasonably reliable means of assessing COP trajectory, the method of its use in research varies considerably (Lafond et al., 2004). To date there is no agreed standardised method that reliably assesses postural stability using a force plate. Differences exist regarding subject head, arm and/or feet positioning, subjects footwear, the number and length of trials (ranging from 8 seconds to 3 minutes with majority at 30 seconds) as well as the COP parameters of interest (Bauer et al., 2008; Corriveau, Hebert, Prince, & Raiche, 2000; Hadian et al., 2008; Lafond et al., 2004; Le Clair & Riach, 1996; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996; Santos, Delisle, Lariviere, Plamondon, & Imbeau, 2008).

Several force plate outputs have been established that aim to quantify postural stability (Lafond et al., 2004). COP is the most commonly used output and is defined as the point application of ground reaction forces under ones feet (Lafond, 2004). Postural sway and COP displacement are mutually dependant and therefore influenced by similar factors such as age, sensory conditions, life-style factors and pathology (Demura, Kitabayashi, Kimura, & Matsuzawa, 2005; Hadian et al., 2008; Lafond et al., 2004; Lin et al., 2008; Mientjes & Frank, 1999; Mizrahi, Solzi, Ring, & Nisell, 2006; Mok, Brauer, & Hodges, 2004; Nies & Sinnott, 1991; Nieschalk et al.,

1999; Nosaka, 2002; Overstall, Exton-Smith, Imms, & Johnson, 1977). Changes in COP position or increased postural sway can be therefore be used to make inferences about the integrity of neurological and biomechanical mechanisms of postural control (Lafond, 2004; Winter, 1995). These changes can be represented by several parameters including; amplitude or velocity based measures, length of COP trajectory path and the total area of COP deviation (Kuukkanen, 2000) each have shown varying degrees of reliability in previous studies (Lafond, 2004). The COP parameters used in this study are *Average Speed (medial/lateral & anterior/posterior)*, *Length of COP path*, *Area of COP path* and *RMSa*, chosen based on their common use in reliability studies and the results obtained from this research (Bauer et al., 2008; Hadian et al., 2008; Lafond et al., 2004; Lin et al., 2008; Pinsault & Vuillerme, 2009).

The primary objectives of this study were; to determine the intra- and inter-session reliability of COP -based measures of postural control in normal subjects using a Medicauteurs *S-Plate* force platform and secondly; to establish a standardised protocol to reliably measure postural stability that can be easily repeated at a tertiary teaching facility. A carefully selected amalgamation of previously pursued protocols was used to design the standardised method used in this study (Bauer et al., 2008; Doyle, Hsiao-Wecksler, Ragan, & Rosengren, 2007; Hufschmidt, 1980; Lafond et al., 2004; Le Clair & Riach, 1996; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996; Santos et al., 2008). Variable factors considered were; the number of examiners (one), the number and length of trials, testing environment, and positioning of each subject were standardised to ensure consistency within and between sessions. All testing was completed in eyes open and eyes closed conditions to investigate the influence of vision on the reliability of postural stability measurements (Santos et al., 2008).

Additionally, this study aimed to investigate the relationship between subjective pain intensity and anthropometric characteristics and postural stability in this sample population. There is evidence that chronic low back and neck pain (Dehner, 2008; (della Volpe et al., 2006; Demura et al., 2005; Hamaoui et al., 2004; Harringe et al., 2008; Leitner et al.; Mientjes & Frank, 1999; Nies & Sinnott, 1991; Radebold et al., 2001) and various anthropometric characteristics (Kejonen, Kauranen, & Vanharanta, 2003) have a significant effect on postural stability. In this study subjective pain intensity, age, gender, height, shoe size and body mass index were recorded in this study in order to observe their possible influence on stability.

## **LITERATURE REVIEW**

### **1. BODY POSTURE**

Body posture is the product of several assembled segments and their masses held together by flexible joints and controlled by the neuromuscular system (Herrington & Davies, 2005; Massion, 1994). It has been suggested that ideal posture occurs when all body segments are aligned vertically and the line of gravity passes through all joint axes (Kendall, & McCreary, 1993; Woodhull, Maltrund, & Mello, 1985). This involves the alignment of several external reference points including the ear lobe, acromial process, greater trochanter and points slightly posterior to the midline of the knee and anterior to the lateral malleolus (Griegel-Morris, 1992; Ward, 2003). However, this ideal is near impossible to obtain (Kendall & McCreary, 1993; Woodhull et al., 1985). Research has shown a high incidence of postural abnormalities within any given population including a forward head, anterior shoulders, excessive spinal curves, and asymmetrical shoulders (Griegel-Morris, 1992). An ideal posture requires minimal energy input as counter-torques created by passive ligamentous tension and muscle activity counteract the gravitational forces that continuously act upon the body (Griegel-Morris, 1992; Woodhull et al., 1985). Thus, even ideal posture is accompanied by a fluctuation of the centre of gravity around an ideal postural set point individual to each person (Woodhull et al., 1985).

Centre of mass is a term often used within posturology and defined as the point equivalent of the total body mass in the global reference system (Winter, 1995). It is the calculated average of each body segment's centre of mass in 3D space (Winter, 1995). Typically, the body's centre of mass lies at approximately the level of the second sacral vertebrae during biomechanical assessment (Norokin & Levangie, 1992). A vertical projection of the centre of mass should fall between an individual's base of support and is known as the centre of gravity (Winter, 1995).

The terms 'centre of gravity' and 'centre of pressure' are often confused and used as if they are or mean the same (Winter, 1995). The Centre of Pressure (COP) is

the point location of the vertical ground reaction force vector. It is calculated as the average of all pressures lying within the surface area in contact with the ground (Winter, 1995). To help identify the differences between centre of gravity and COP, research was conducted to show the movement and relationship of the two measures during upright bipedal stance (Winter, 1995). This research identified that the COP and centre of gravity are inversely proportional. For instance, as the centre of gravity deviates anteriorly, the COP will move posteriorly in order to control and maintain the centre of gravity positioning during stance. It is apparent that the movement of the COP must always be greater than that of the centre of gravity in order to maintain equilibrium. Thus, a deviation of the centre of gravity to within a few centimetres of the toes may not be able to be corrected by an extreme movement of the COP. Therefore stepping is necessary to prevent falling (Winter, 1995).

## **1.2 Functions of Posture**

Posture serves two main functions within the body. The first is a mechanical antigravity and balance function that the human reference posture (stance) is built upon (Massion, 1994). An antigravity function works to resist ground reaction forces by providing joint stiffness via muscle tone primarily of the extensor antigravity muscles (Massion, 1994). Simultaneously, a balance function works to prevent falling through maintaining the centre of gravity within an individual's relatively small base of support in static conditions (Massion, 1994). In normal standing, it is the postural control system's main function to integrate the antigravity and balance functions of the body (Massion, 1994). Therefore, using joint stiffness and muscle tone to maintain the centre of gravity within one's base of support.

Secondly, posture acts as a reference framework for perception and action of a or several limbs in relation to the external world (Massion, 1994). The positioning and orientation of body segments such as the head, trunk and limbs provide the reference framework for calculating target locations in the external environment as well as the organization of movement toward these targets (Massion, 1994). Maintaining vertical positioning of the head and trunk against the forces of gravity requires adequate postural control and is a necessary function for ideal visual and goal-directed mobility used in everyday living (Hadders-Algra, Brogren, & Forssberg, 1998). Efficient control of basic posture is necessary for even the simplest everyday tasks such as standing and walking (Deliagina, Zelenin, Beloozerova, & Orlovsky, 2007). The

control of posture is a complex task and requires interaction of multiple sensory input systems and motor outputs (Deliagina et al., 2007; Harringe, Halvorsen, Renstrom, & Werner, 2008; Mientjes & Frank, 1999; Radebold, Cholewicki, Polzhofer, & Greene, 2001; Schumann, Redfern, Furman, El-Jaroudi, & Chaparro, 1995). Deficiency in any one of the multiple sensory or motor mechanisms of the postural system can produce dramatic effects on postural stability and motor performance (Deliagina et al., 2007).

When standing, the human body is relatively unstable as it is a tall structure balancing on a small base of support (Massion, 1994). Three main physical factors have been stated to challenge the body's equilibrium during quiet stance. The first being gravity. Secondly, motion of the body's support surface mainly through tilting of the talocrural (ankle) joints and thirdly, external contact forces with the body (Mergner, Maurer, & Peterka, 2003). To compensate for these perturbations while maintaining stance, the body must adopt several control strategies.

## **2. POSTURAL CONTROL**

Postural control is the ability of the body to maintain equilibrium of the centre of mass by counteracting the constant destabilising forces acting on the body (Harringe et al., 2008). It is widely documented that postural control involves the complex interaction of several sensory modalities; visual, vestibular and proprioceptive (Harringe et al., 2008; Mientjes & Frank, 1999; Radebold et al., 2001; Schumann et al., 1995) and specific co-coordinated motor output from many joints (Radebold et al., 2001). The coordinated motor outputs from several joints produce compensatory adjustments to changing posture and act in response to the incoming sensory information (Silfies, Cholewicki, & Radebold, 2003). Although many systems are involved in postural control, balance is primarily a sensory function and not a motor function (Charlotte, Janio, & Andersson, 1989; Guillaume & Goss-Sampson, 2003).

Each of the sensory components of postural control have a unique task. The visual and vestibular systems provide information regarding spatial orientation and perception of motion (Silfies et al., 2003). The somatosensory system refers to the proprioceptors within muscle spindles, golgi tendon organs and joints, along with the mechanoreceptors and gravity receptors responsible for interpreting pressure or shear induced by the body's motion on its supporting surface (Silfies et al., 2003). Collectively, sensory inputs contribute to orientating postural segments with respect

to each other and the external environment (vertical gravity vector) (Massion, 1994). This sensory information provides the feedback to a postural control system regarding current body posture, orientation to the vertical axis and the relationship of the centre of gravity to the body's support surface and motion in space (Silfies et al., 2003).

### **3. THE POSTURAL CONTROL SYSTEM**

The term "postural control system" is given to the complex interaction of the central and peripheral components aimed at controlling posture. Multi-sensory inputs from visual, vestibular, and somatosensory systems contribute to the orientation of postural segments in relation to each other and the external environment (vertical gravity vector). It is these sensory systems that identify any mismatch between intended and actual positions before delivering this information to the brain for interpretation (Deliagina et al., 2007). Should the gravity or orientation of the body axis not be in their desired location, motor commands are sent to the motor cortex to activate the appropriate muscles to maintain the body's centre of gravity within its base of support and thus minimise sway (Deliagina et al., 2007; Karlsson & Persson, 1997; Massion, 1994). One model of the postural control system described it as a closed loop system, as the central nervous system is continuously working in a feedback loop interpreting the actual and perceived orientation of the body (Karlsson & Persson, 1997). The 'postural body scheme' aids in this feedback loop as it is described as an internal representation of the body geometry that is not purely based on sensory information (Massion, 1994). It also deals with the body's kinematics, kinetics and orientation of the body in vertical stance (Massion, 1994). This internal representation is the basis for both the perception of the body's orientation in space and postural reactions involving motor control to maintain equilibrium in vertical stance and an integral part of postural control (Massion, 1994).

#### **3.1 Mechanisms of the Postural Control System**

In order for the postural control system to achieve its antigravity and balance functions during upright bipedal stance, physiological mechanisms ensure several distal joints and muscle groups are in a stable and geometric relationship. It has been estimated that this requires the synchronised control of more than 700 muscles and a multi-link system including more than 200 degrees of freedom controlled by the neuromuscular system (Era, Schroll, Ytting, Gause-Nilsson, Heikkinen, Steen, 1996; Massion, 1994). The human body maintains quiet upright stance through brief periods

of muscular action that punctuate longer periods of muscular silence (Simoneau, Ulbrecht, Deri, & Cavanagh, 1995). This phasing of muscle activity is controlled by a combination of central and peripheral components including supra-spinal commands and spinal reflexes and the integration of afferent and/or efferent signals of the visual, vestibular and somatosensory systems respectively (Alexander & La Pier, 1998; Simoneau et al., 1995; Winter, 1995). The collaboration of both components can be termed postural reactions.

### ***3.1.1 Central Components - Hindbrain reflexes and Postural Control***

#### ***3.1.1.1 Spinal reflexes***

Research has shown quadruped animals, despite a decerebration, will retain their righting reflex to return to their dorsal side up reference posture (Deliagina et al., 2007). This reflex has been shown with a decerebrated animal passively positioned on its side rapidly resuming a dorsal side up posture (Deliagina et al., 2007). Because this reflex resumes after decerebration, it indicates that an essential part of the nervous mechanisms working to control basic posture is located below decerebration level directing research to either the brain stem, cerebellum or spinal cord (Deliagina et al., 2007).

To identify cerebellar and brain stem involvement in postural control, a study utilised electrical stimulation of both sites resulting in strong tone of the anti-gravity (extensor) muscles (Deliagina et al., 2007). The descending reticulospinal and vestibulospinal pathways are involved in this effect (Deliagina et al., 2007; Marieb & Hoehn, 2007). In addition, when monitoring single neuron recordings of a cat walking on a treadmill, the activity of the descending tracts of the vestibulospinal and reticulospinal pathways showed a direct correlation with the degree of treadmill tilt (Deliagina et al., 2007) further demonstrating the involvement of the cerebellum and brain stem. It is unclear whether the activity of the descending tracts brought on by tilt is responsible for generating postural corrections or used only to modulate the postural responses produced by spinal mechanisms (Deliagina et al., 2007).

#### ***3.1.1.2 Supra-spinal commands***

Supra-spinal tonic drive derived from the brain stem is addressed by the spinal postural mechanisms via two sources (Deliagina et al., 2007). The first is the

command system for activation of spinal postural mechanisms (Deliagina et al., 2007). Activation of these mechanisms via excitatory drive from the brainstem results in the increased tone of the anti-gravity (extensor) muscles and postural reflexes occur (Deliagina et al., 2007). The second source involves a command system that initiates modifications of stabilised body configuration. In order to maintain balance while altering body configuration, the tonic activity of one or several limbs must be modified (Deliagina et al., 2007).

The nervous system is responsible for the organising motor patterns into basic and/or direction specific motor patterns. Direction specificity refers to the activation of certain muscles during a perturbation of the body in a specific direction (Hadders-Algra et al., 1998). For example, during a sudden forward sway of the body in sitting or standing, the dorsal muscles are activated primarily, whereas a posterior sway primarily involves the ventral muscles. These basic direction specific muscle activation patterns can be altered depending on the multi-sensory inputs of the visual, vestibular and/or somatosensory systems (Hadders-Algra et al., 1998). The latter of the three most likely being the most important in normal stance conditions (Hadders-Algra et al., 1998). It has been proposed that a central pattern generator is responsible for the neural organization of postural adjustments. This model has two functional levels which are responsible for muscle pattern selection and the control of fine tuning the selected pattern to task specific multi-sensorial information (Hadders-Algra et al., 1998).

### ***3.1.1.3 Spinal postural reflexes***

Truncal stabilisation involves the interaction of spinal and supra spinal levels. There are two closed-loop neural mechanisms named loops L1 and L2 (Deliagina et al., 2007). Loop L1 resides in the spinal cord and driven by inputs from the limb mechanoreceptors (Deliagina et al., 2007). Loop L1 functions to compensate for postural disturbances by producing corrective motor responses (Deliagina et al., 2007). Loop L2 resides primarily in brain stem and cortex are, like loop L1 driven by limb mechanoreceptors but also receive information regarding head orientation from the visual and vestibular systems (Deliagina et al., 2007). The output of this mechanism is a phasic corrective command presented to spinal mechanisms via different descending pathways including the reticulospinal and corticospinal which elicit postural correction (Deliagina et al., 2007).

### ***3.1.2 Peripheral Components of Postural Control***

#### ***3.1.2.1 Visual system***

Visual information is delivered via the retina to at least two locations within the brain. The pathways used for information to reach these points are assumed to be specialised for different purposes; the focal system for object identification and the ambient system for movement control (Kejonen, 2002). The ambient system has shown to strongly influence stability and balance. Vision influence on postural control comes as the result of a relative shift of an image on the retina, which initiates compensatory motor reactions of the body including muscle activation for postural correction (Kejonen, 2002). The effectiveness of vision on postural control is dependant on visual acuity, visual contrast, object distances and room lighting. It has been shown that the visual system works best when the visual distance is less than two metres (Kejonen, 2002).

#### ***3.1.2.2 Somatosensory system***

Proprioceptive input originates from the proprioceptive and exteroceptive receptors located in joints, muscles, tendons and skin collectively known as the somatosensory system (Schiowitz & DiGiovanna 2004). These sensory receptors provide information related to body and limb position as well as the distension of the respective muscles (Kejonen, 2002). Muscle spindles (type Ia and II), Golgi tendon organs (Ib) and joint receptors provide proprioceptive input while exteroceptive information is derived from pressoreceptors located primarily within the cutaneous and subcutaneous tissues of the sole of the foot (Kejonen, 2002). The main types of exteroceptive receptors are the superficial Meissner corpuscles, Merkel disks and the deep laying Ruffini endings and Pacinian corpuscles (Kejonen, 2002).

Muscle spindles provide information regarding change in muscle length and/or tension. Alternately, they can be activated by passive stretch applied to the entire muscle (Schiowitz & DiGiovanna 2004). The intrafusal fibres within the muscle spindles receive efferent input via the  $\gamma$  motoneuron (Kejonen, 2002; Schiowitz &

DiGiovanna, 2004). It is the pressoreceptors that detect body sway while mechanoreceptors determine site and velocity of skin deformation as well as acceleration and pressure changes (Kejonen, 2002). The role of joint capsule receptors in postural control are still unknown however they do provide information regarding the position and movements of body parts in relation to one another (Kejonen, 2002).

Proprioceptive input is essential for postural control as information gained at the ankle joints and resultant torque through counteracting destabilising forces working at this joint is critical to maintain bipedal stance (Kejonen, 2002). Information derived from the cervical muscles provide references of head movement in relation to the trunk and it has been suggested that the eye muscles reflect the eyes position in relation to the head (Kejonen, 2002).

### ***3.1.2.3 Vestibular system***

The vestibular system consists of two frequency selective acceleration sensors, angular and linear pertaining to the semilunar canals and utricular otoliths respectively (Nashner, 1971). The semilunar canals are particularly sensitive to change in movement velocity at a frequency between 0.2 to 10Hz and therefore active mainly at the initiation and ending of a movement (Kejonen, 2002). Linear sensors (Utricular otolith organs) are responsible for identifying orientation of the body in respect to vertical and capable of stabilising low frequency drift of the body, less than 5Hz (Nashner, 1971).

Due to the human body being an inherently unstable structure during both upright stance and locomotion, a high sensitivity to sway in all frequencies is necessary. This allows for rapid maneuverability important for survival (Nashner, 1971). With this come rapid angular motions, which conflict with messages of linear acceleration from the utricular otoliths and the gravitational stimuli. To reduce sensory confusion, the semilunar canals contain angular motion sensors that provide unambiguous motion sensation but poor static sensitivity (Nashner, 1971). The linear motion sensors are therefore restricted to very low frequency movements and so primarily responsible for the detection of any postural disturbance during unperturbed upright stance (Nashner, 1971).

Information from the otoliths and semicircular canals is transmitted via the vestibular nuclei located in the midbrain. The vestibulospinal pathway is responsible for the compensatory reactions of the lower leg musculature involved in postural

control. Thus, the vestibular postural control model incorporates the theories of ankle joint strategy and body sway regarding the generation of torques by the lower leg musculature and the identification of body sway by the angular and linear acceleration sensors (Nashner, 1971).

The role of the vestibular system during quiet stance is mainly to solve problems of differing sensory information. It has been found that chronic vestibular insufficiencies are relatively well compensated for during quiet stance by vision and proprioception. However, in stating this, it has been found that the body is unable to completely compensate for the absence or alteration of any one system (Simoneau et al., 1995).

Of the three sensory systems involved in postural control, although each is important, some are more influential to postural control than others. Studies have been conducted which challenge the postural control system by either experimentally altering or completely removing one or more of the sensory systems (Simoneau et al., 1995) or through the use of subjects with visual, vestibular or proprioceptive deficits (Allum, Bloem, Carpenter, Hulliger, & Hadders-Algra, 1998; Horstmann & Dietz, 1988; Simoneau et al., 1995). This allows correlations to be made between COP movement and the degree of input from one or more systems. One study that individually challenged each of the sensory systems found the removal of the somatosensory system to create the greatest percentage increase of COP movement (66%) followed by the visual system (41%) and to the least extent the vestibular system (4%) (Simoneau et al., 1995). Interestingly, the removal of both visual and vestibular input had less consequence on COP movement than removal of the somatosensory system alone. Thus indicating the somatosensory system to have the greatest influence over control of COP of all sensory systems (Simoneau et al., 1995).

#### ***3.1.2.4 Postural reactions***

Postural reactions can be divided into two principle modes. The feedback mode, that compensates for any movement away from that of the desired posture and the feed-forward mode responsible for the anticipatory postural adjustments that counteract any destabilising consequences of voluntary movement (Deliagina et al., 2007). During bipedal stance, postural control primarily functions within the feedback mode. This mode is then categorised into two major concepts regarding the functional organization of the postural control system (Deliagina et al., 2007).

The first concept is based on the idea of a control theory. This theory suggests body posture is depicted by a regulated variable (Deliagina et al., 2007). Whether this variable is the COP or the orientation of the vertical body axis, a particular value of this variable is stabilised. In accordance with this theory, information regarding head and body orientation is delivered via several modalities including vestibular, visual and proprioceptive sensory inputs. From here, the information is interpreted and integrated to form a generalised depiction of body posture and the regulated variable. Should the regulated variable alter from its desired value, motor responses are stimulated to elicit a corrective movement (Deliagina et al., 2007).

The second concept is reflex based and founded on the theory that stabilised postures are the result of interactions of several reflexes in accordance to sensory inputs from the vestibular, visual and somatosensory systems. These results can either supplement or counteract each other (Deliagina et al., 2007).

## **3.2 The Corrective Motor Process**

### ***3.2.1 Ankle and hip strategy models***

Like any afferent sensory information, it all must be interpreted and if need be, acted upon. Even during controlled stance, a small amplitude slow speed sway occurs as a result of the interplay between destabilising forces acting upon the body and the actions of the postural control system (Pavol, 2005). Healthy individuals generally portray a slow speed, slow amplitude sway which indicates an effective postural control system (Kuukkanen, Malkia, 2000). To maintain stance, muscles are recruited from distal to proximal to ensure body movement is simultaneous with the head. The ankle acting as the fulcrum is the basis of the ankle strategy theory and is responsible for maintaining equilibrium of the centre of mass (Mok, Brauer, & Hodges, 2004; Nies & Sinnott, 1991).

When stance is perturbed in a sagittal plane, two strategies are utilised to maintain balance with minimal effort. Ankle strategy is primarily used in quiet stance and small perturbations (Winter, 1995). This strategy involves solely the ankle plantar and dorsiflexor muscles to control the 'inverted pendulum'. The inverted pendulum description eludes to the body's rotation about the talocrural joints in a sagittal plane seen in quiet upright stance.

When the body is faced with a perturbation beyond which the ankle can compensate and the centre of gravity edges towards the outer limits of the base of support, the hip strategy is employed (Winter, 1995). Muscles are recruited from proximal to distal to encourage redirection of the centre of gravity in the opposite direction of the trunk deviation (Winter, 1995). The hip either flexes to posteriorise the centre of gravity, or extend to anteriorise this point (Winter, 1995). The hip load/unload strategy controlled by the hips adductor and abductor muscles has also shown to be the primary defense in a medial/lateral direction when standing with feet side by side (Winter, 1995). Major perturbations or damage to the feedback system may encourage additional strategies including knee or arm movement (Winter, 1995). Failing this, stepping is the last resort utilised to prevent falling (Winter, 1995).

Interestingly, the roles of the ankles and hips reverse while in tandem stance (one foot in front of the other) (Winter, 1995). Medial/lateral balance is an ankle mechanism involving the invertor and evertor muscles while the hips load/unload strategy dominates in the anterior-posterior plane (Winter, 1995). If the centre of gravity exceeds the limits of the base of support, the surface area is increased by stepping (Nies & Sinnott, 1991).

#### **4. POSTURAL SWAY**

During bipedal stance, the centre of mass oscillates over the base of support in response to internal and external perturbations (Alexander & La Pier, 1998; Kuukkanen & Malkia, 2000). This oscillation is known as postural sway (Alexander & La Pier, 1998). Postural sway is measured through the change in COP positioning over time. These changes can be represented in different ways including; the speed of COP movement, the length of the COP's path and the total or confidence ellipse area of the COP's path. Instruments utilised to assist in the measurement of COP deviation include primarily force plates but also video footage.

The human body's centre of mass is at approximately two thirds the body height making it inherently unstable during upright stance unless the postural control system is continuously functioning (Winter, 1995). Sagittal and/or coronal sway occurs spontaneously as a result of this instability and the continual presence of internal and external destabilising perturbations (Karlsson & Persson, 1997). It has been reported that sagittal sway is larger than sway in a coronal plane with a ratio of approximately 1.5 during both vision and non-visual conditions. This ratio has been

used to identify individuals with proprioceptive, vestibular, and/or cerebellar abnormalities compared to normal individuals (Suomi & Kocejka, 1994).

Numerous factors and disorders can adversely affect postural sway by altering the ability of the body to adapt to changing stimuli. Thus increasing both postural and the energy expenditure required to maintain upright stance (Alexander & La Pier, 1998). These interruptions of the balance control system may lead to abnormal postural response patterns, impaired reaction times, and instability or unsteadiness (Alexander & La Pier, 1998).

#### **4.1 The Sensitivity of Postural Stability to Multiple Factors**

Many studies have since provided evidence of several disorders that affect postural stability as shown by increased sway. The study of postural stability and sway was developed as a means to determine the functional capability of the regulation of balance (Dehner et al., 2008). Using a force plate, it is possible to determine the shift in weight through each of the lower extremities whilst standing (Dehner et al., 2008). From this, information regarding balance and stability can be gained.

Numerous factors including biometric factors, physiological functions, cognitive processing, visual feedback and cerebellar activity have shown to influence postural sway (Allard, Nault, Hinse, Blanc, Labelle, 2001; Kejonen, Kauranen & Vanharanta, 2003). Due to the vast array of subcategories within these factors, it emphasizes the vulnerability of the postural control system to a variety of natural life processes, pathologies, injuries, or external factors. In light of this, the difficulty of obtaining a truly standardised procedure while measuring sway is highlighted as it is affected by countless variables.

Many of these variables are uncontrollable and typically associated with aging. As previously stated, the maintenance of upright posture is a demanding task for the postural control system (Era et al., 1996). With age comes a natural reduction in processing speed of the supra-spinal mechanisms as part of the central component of postural control. This is thought to explain in part why increased sway is observed within the elderly population (Era et al., 1996). The following age-related disorders have shown to significantly increase postural sway when compared to younger controls, poor orthostatic control, Alzheimer disease (Claydon, 2005; Horak, 1989; Overstall, Exton-Smith, Imms, Johnson, 1977), uni or bilateral vestibular organ

dysfunction (Demura, Kitabayashi, Kimura, Matsuzawa, 2005), central nervous system dysfunction including Parkinsons disease, labyrinthine vertigo and hemiplegia (Mizrahi, Solzi, Ring, Nisell, 2006), brainstem disease and cerebellar dysfunction due to the role of the cerebellum in balance tasks (Horak, 1989; Marvel, 2003).

External factors shown to influence sway primarily include drugs, alcohol, sleep deprivation, muscle fatigue and injury. Psychoactive medications such as Diazepam despite relatively small doses have shown to increase sway for up to 5 hours after ingested (Robin, 1991). This was particularly evident within the elderly population (Swift, 1985). A Japanese study compared postural sway in sleep deprived, overworked individuals (longer overtime workers) and controls (regular full time employment). Longer overtime workers slept five hours or less per night and working on average at least 80 hours of overtime per month for least 6 months. Controls worked on average 40 hours per week. The study found significant increases of amplitude and speed of COP fluctuation in the longer overtime workers group compared to controls indicating that physical and emotional distress as well as sleep deprivation to be very influential on postural control (Kanae, 2005). The mean area and velocity of COP are significantly larger when lumbar extensor muscles are fatigued to 60% (Davidson, 2004). Similar findings have been explained concerning cervical musculature fatigue and postural sway (Treleaven, 2008). Zingler Carina et al (2007) & Pereira (2001) found nicotine to have a significant effect on sway in non- or occasional smokers. Caffeine can increase sway between 1 to 3 hours after ingestion (Claydon, 2005). Similarly, low to moderate alcohol ingestion with a blood alcohol to a level between 0.22 and 1.59‰ can significantly increase sway (Nieschalk, Ortmann, West, Schmal, Stoll, Fechner, 1999). Recent ankle sprains and anterior cruciate ligament injury have been shown to significantly increase postural sway (Cornwall, 1991; Hadian et al., 2008; Salavati, M., Hadian, M. R., Mazaheri, M., Negahban, H., Ebrahimi, I., Talebian, S., et al. 2009). This is likely due to the disruption within the proprioceptive system linked with ligamentous damage.

#### ***4.1.1 The Effect of Pain on Postural Stability***

Posturographic investigations have identified patients with chronic pain, whether it neck or lower back, to demonstrate impaired balance regulation when compared to asymptomatic individuals (Dehner et al., 2008; Mientjes & Frank, 1999;

Nies & Sinnott, 1991). Structural aspects including; acquired or degenerative facet joint pathologies, whiplash and intervertebral disc dysfunction have said to account for up to 84% of chronic neck pain cases and is linked as a causative factor for distortion or disruption of the postural control system (Dehner et al., 2008). The psychological effects of chronic pain have also been suggested to be detrimental to postural control due to their affect on the central nervous system's modulation of proprioceptive afferent information (Dehner et al., 2008).

#### ***4.1.1.1 Neck pain***

Sensorimotor control of upright stance, head and eye movement relies on afferent information from the visual, vestibular and proprioceptive systems that converge in several areas of the central nervous system (Treleaven, 2008). Within the cervical spine lay numerous mechanoreceptors responsible for providing proprioceptive input as well as the central and reflex connections with the visual, vestibular and central nervous system (Treleaven, 2008). The suboccipital muscles attach from the base of the skull to the first one or two cervical vertebrae. They contain a high density of muscle spindles that contribute to the highly proprioceptive function of the upper neck (Treleaven, 2008). The suboccipital and other cervical musculature functions to relay and receive information to and from the central nervous system as well as houses specific connections from the cervical receptors to the sympathetic nervous system, visual and vestibular apparatus (Treleaven, 2008). Cervical afferents also contribute to three reflexes involved in head, eye and postural stability; the cervico-colic reflex responsible for neck muscle activation in response to stretch to maintain head position, the cervico-ocular reflex which works in conjunction with the vestibuloocular and optokinetic reflex to activate extraocular muscles assisting in maintaining clear vision on head movement and the tonic neck reflex integrated with the vestibulospinal reflex for postural stability.

The importance of these reflexes is highlighted by the disturbance of sensorimotor control in neck disorders including muscular fatigue, whiplash (Dehner et al., 2008; Schieppati, Nardone, & Schmid, 2003; Treleaven, 2008). Nystagmus, disequilibrium and severe ataxia have been induced in asymptomatic individuals following sectioning of the cervical nerves or anaesthetic injections to the cervical area (Treleaven, 2008). Change in head and eye position, increased body sway, and altered velocity and direction of gait have been brought about by using vibration to

the cervical muscles stimulating muscle spindle afferents as has sustained isometric muscle contraction inducing fatigue (Treleaven, 2008). This is thought to be due to a mismatch between abnormal cervical afferent information and the normal vestibular and visual system information (Treleaven, 2008). Sufferers of neck pain can also experience disturbed cervical joint position sense, oculomotor control and postural stability.

#### ***4.1.1.2 Low back pain***

A preliminary study in the field of postural sway and lower back pain found subjects with lower back pain to have significantly increased body sway (Mientjes & Frank, 1999; Nies & Sinnott, 1991). This could be explained by altered sensory inputs such as proprioception and distorted motor responses either due to decreased muscle strength or motor coordination (Alexander & La Pier, 1998). Within symptomatic individuals, three common factors have been observed; a posterior COP position, greater utilisation of the hip/back strategy rather than ankle strategy particularly on difficult postural tasks and poor single-footed balance with eyes closed due to inability to move the centre of pressure over the weight bearing limb (Mientjes & Frank, 1999; Nies & Sinnott, 1991). Furthermore, lower back pain sufferers have shown to have defective activity and morphology of deep abdominal and paraspinal muscles and augmented superficial abdominal muscles (Mok et al., 2004; Nies & Sinnott, 1991).

The first of the common factors observed in symptomatic individual is a posterior positioning of the COP when standing on a flat surface. This has been suggested to be the result of adopting an analgesic hyper-lordotic posture (Mok et al., 2004; Nies & Sinnott, 1991). This analgesic posture is commonly adopted as it relieves pain by allowing trunk extensor muscles to relax (Mok et al., 2004; Nies & Sinnott, 1991). However, simultaneously this posture also increases compression through the posterior aspect of the vertebrae and narrows the foramen where nerve roots exit the spinal canal (Nies & Sinnott, 1991). It is plausible from an osteopathic perspective that zygapophyseal joint impaction and/or irritations can lead to acute and/or chronic back pain. Due to the narrowing of the intervertebral foramen, nerve root irritations can develop creating radicular or radiculopathy along the associated nerve root or dermatome. Furthermore, long-term inappropriate loading can stimulate bony osteophytic growth particularly around the zygapophyseal joints consequently

structurally narrowing the foramen further. Zygapophyseal joint irritations equate for approximately 15-40% of low back pain cases (Bogduk, 1998). In light of this, would it be then be reasonable to concur that many individuals presenting to an osteopath or manual therapist with lower back pain and the compensatory hyper-lordosis to therefore have increased postural sway? Posterior positioning of the COP inhibits the small rhythmical circling motion that occurs about the ankle during upright stance. This is known as the ankle strategy, simply explained as the body swaying like an inverted pendulum during upright stance. As this method is inhibited due to altered COP position, the hip and back are incorporated to stabilise the COP within the base of support. For this, trunk movement about the limbs is required rather than limb movement on the trunk, which increases sway amplitude (Mok et al., 2004; Nies & Sinnott, 1991).

Deficits in lumbar spine proprioception have been reported in individuals with lower back pain. As proprioceptive feedback is not only one of the peripheral components of postural control but also an essential part of posture, when it gets interrupted or dysfunctional postural control is also affected. Poor lumbar spine proprioception has been linked to poor balance control (Mok et al., 2004) as well as delayed muscle response upon sudden trunk loading in individuals with lower back pain (Radebold et al., 2001). Supporting these findings are studies showing individuals with lower back pain to have poor lumbar spine positional sense and slower psychomotor speed (Hodges, 1996; Luoto et al., 1996; Radebold et al., 2001).

Postural activity of the truncal muscles is altered in individuals with acute or chronic back pain (Nies & Sinnott, 1991). Evidence shows consistent deficits and dysfunction of the deep abdominal and paraspinal muscles are often accompanied with excessive compensatory activity of the superficial trunk muscles (Mok et al., 2004). Traditional theories claim insufficient functioning of trunk muscles to lead to increased stress and load on spinal segments and ligaments (Radebold et al., 2001). However, research has failed to confirm this theory (Radebold et al., 2001). Poor posture has been shown to alter the physiological structure within the muscles deeming them weak or stretched, typically after a muscle has been held in a stretched position for a sustained period of time (Mulhearn & George, 1999). Lengthening of a muscle by this method can result in decreased power in mid-range of motion, early onset of fatigue and poor stability (Mulhearn & George, 1999).

A study by Mientjes & Frank (1999) found medial/lateral sway in chronic low back pain sufferers to be significantly increased when compared to asymptomatic controls in 5 out of 7 tasks. ICC values ranged from 0.41 to 0.89, indicating moderate to excellent reliability. This study also highlighted the differences in reliability between medial/lateral and anterior/posterior sway as the latter was only increased in 2 of 7 tasks. Typically, tasks performed with eyes closed portrayed increased postural sway as visual cues were eliminated (Mientjes & Frank, 1999). These findings were consistent with Byl & Sinnott (1988) who found significantly increased sway in the frontal plane in individuals with a variety of low back pain complaints when compared to healthy controls.

Contrary to these studies, Hamaoui et al (2004) revealed greater displacement of the COP along the sagittal axis (anterior/posterior) in low back pain subjects than the healthy controls in three of four conditions tested. These positions were eyes-closed feet-spread, eyes-open feet-together and eyes-open feet-together excluding eyes-open feet-spread (Hamaoui, Do, & Bouisset, 2004). The greatest difference was found in eyes-closed feet-together conditions where the lower back pain group obtained significantly larger sway recordings than their controls (Hamaoui et al., 2004).

## **4.2 Implications of Increased Postural Sway**

Most people pay little attention to balance until it becomes compromised usually through injury and/or aging, resulting in the feeling of instability and vulnerability as well as predisposing falls (Schumann et al., 1995). As mentioned earlier, many factors and disorders can adversely affect postural sway by altering the ability of the body's control system to adapt to changing stimuli, thus increasing both sway and the energy expenditure necessary to maintain upright stance (Alexander & La Pier, 1998). To date, no studies have suggested or researched treatment options for increased postural sway. Due to the numerous causative factors of altered or increased postural sway it would seem impossible that a single treatment regime would provide a solution. Manual therapy including osteopathy may be able to assist in this field particularly in cases where chronic pain or injury are the causative factors.

### ***4.2.1 Implications of Postural Sway to Osteopathy***

Research has shown that individuals experiencing chronic low back or neck pain exhibit compromised postural control shown by increased postural sway when compared to asymptomatic control subjects (della Volpe et al., 2006; Hamaoui et al., 2004; Harringe et al., 2008; Mientjes & Frank, 1999; Nies & Sinnott, 1991; Radebold et al., 2001). As lower back and neck pain account for a large proportion of patient complaints seen within manual therapy, it suggests that a significant proportion of patients seen by osteopaths may have compromised postural control and increased sway. Physical assessments performed by manual therapists typically consist of observation, range of motion testing, strength, function, posture and biomechanical assessment. A rudimentary screen of balance or weight bearing is sometimes included however, not routinely performed by manual therapists despite it being an essential aspect in the performance of daily activities (Alexander & La Pier, 1998).

In order to maintain balance during daily activities, central and peripheral components of nervous control interact to ensure the centre of gravity stays within one's base of support (Alexander & La Pier, 1998). The central nervous system acts to integrate the peripheral components namely the proprioceptive, visual and vestibular inputs components and selects the most appropriate muscular responses to control body position and posture (Alexander & La Pier, 1998). Conversely, any problem with any of the above-mentioned components potentially results in balance dysfunction (Alexander & La Pier, 1998). Although, research has yet to prove the effect of osteopathy on visual or vestibular dysfunction, the somatosensory system is able to be influenced through osteopathic intervention (Schiowitz & DiGiovanna, 2004).

Osteopathy is a holistic form of manual therapy concerned with all aspects of health including; physical, psychological and spiritual well-being. The practice of osteopathy aims to restore the health of an individual through re-establishing equilibrium within the body (Schiowitz & DiGiovanna, 2004). Equilibrium is susceptible to disruption through various means. An example of this being disordered proprioceptive feedback as the result of somatic dysfunction or injury such as recurrent ankle sprains (Schiowitz & DiGiovanna, 2004). Many of the body's proprioceptive organs lay within the joint capsules, muscles, tendons and skin all of which are involved within an osteopathic treatment (Schiowitz & DiGiovanna, 2004). Several techniques utilised by osteopaths aim to 'reset' or restore proper proprioceptive feedback to or about a joint. Not only appendicular but also axial joints

provide proprioceptive input to the central nervous system supported by studies that have identified spinal manipulation to have a direct influence on the proprioceptive system (Albuquerque-Sendin, Fernandez-de-las-Penas, Santos-del-Rey, & Martin-Vallego, 2009). In those with neck pain, spinal manipulation has shown to impact proprioceptive sensibility possibly by the afferent inputs facilitated by joint manipulation inducing alterations in the proprioceptive stimuli hence affecting postural control (Albuquerque-Sendin et al., 2009). The majority of studies concerning manipulation and the proprioceptive system have been spinal focused as apposed to appendicular joints (Albuquerque-Sendin et al., 2009).

## **5. THE FORCE PLATE AS A MEASUREMENT TOOL FOR POSTURAL STABILITY**

In order to establish these differences in sway between individuals, the force plate has been used commonly for quantitative balance measurement. It is used to evaluate the functioning of the postural control system in both static and dynamic conditions (Bauer et al., 2008; Era et al., 1996). From a force plate, postural sway is commonly assessed through recording the trajectory of the COP over a period of time. Sway measurements can be quantified from force plate readings using amplitude or velocity based measures, the length of the COP's path, and total area of COP movement (Kuukkanen & Malkia, 2000). Such parameters have identified differences in sway within age groups, sensory conditions, pathology and been linked to the risk of falls (Demura et al., 2005; Hadian et al., 2008; Lafond, et al., 2004; Lin et al., 2008; Mientjes & Frank, 1999; Mizrahi, Solzi, Ring, & Nisell, 2006; Mok et al., 2004; Nies & Sinnott, 1991; Nieschalk et al., 1999; Nosaka, 2002; Overstall et al., 1977).

Despite their common use in studies such as these, force plates are subject to measurement errors that include 3 types of variability; intra-session, inter-session retest and inter-rater (Bauer et al., 2008). Intrasession reliability is the immediate test re-test reliability related to the random variability of the measurement. Intersession reliability is the reliability between measures over a set time frame (days, weeks, months). Inter-rater reliability is in regard to the examiner and their protocol and procedures of data collection.

### **5.1 Monitoring Changes of the Centre of Pressure (COP)**

Tracking COP position using a force plate is a common and easy method for measuring postural stability (Sampson & Crowe, 1996). The COP is defined as a point location of the vertical ground reaction force vector. This is calculated as a weighed average of all pressures within the surface area in contact with the ground (Winter, 1995). In bilateral stance, the net COP falls between the two feet but varies depending on weight distribution being taken by each foot (Winter, 1995). During unilateral stance, the COP will fall within the surface area of that foot. Net COP is used when measuring COP in bilateral stance on a single force plate (Winter, 1995). The location of the COP under each foot is a direct representation of the neural control of the muscles that control the talocrural (ankle) joint (Winter, 1995). For example, during plantar flexion the COP moves anteriorly while dorsiflexion will posteriorise this point. Inversion and eversion of the talocrural joints move the COP laterally.

Movement of the COP in both anterior-posterior and medial-lateral planes represents the effectiveness of the postural control system to maintain quiet stance. In non-pathological states small amplitude, low speed oscillations during quiet stance are considered to be a reflection of the body's balance ability. This indicates the effectiveness of the postural control system as little effort is necessary to maintain posture (Era et al., 1996).

## **6. RELIABILITY OF POSTURAL SWAY MEASURES**

Within reliability studies there are several types (intra-session, inter-session, inter-examiner, and intra-subject). Intra-session reliability refers to the consistency or reproducibility of a measure within one session and in this case in aim to establish the usefulness of a method and the chosen COP outcomes. This type of reliability is important when determining the effectiveness of an intervention (Bauer et al., 2008; Corriveau, Hebert, Prince, & Raiche, 2000; Hadian et al., 2008; Lafond et al., 2004; Lin et al., 2008; Nies & Sinnott, 1991; Santos et al., 2008). Inter-session reliability refers to the reproducibility of measurements between multiple sessions, usually on different days, in order to establish the usefulness of a measure. Few studies have been conducted regarding inter-session reliability of COP -based measures, whether this at intervals of hours, days or weeks (Lafond et al., 2004; Lin et al., 2008). Inter-examiner reliability is the term given to the reliability of different examiners to conduct a method consistently throughout a study. However in COP-based postural control studies, due to the simplicity of equipment such as force plates, the task and

instructions, inter-rater variation is unlikely to be problematic (Santos et al., 2008). Intra-subject variation is the most important type of reliability for research as it affects the precision of estimates of change in the variable of an experimental study (Hopkins, 2000).

As mentioned above, quiet standing on a force platform is the most common method to assess the performance of the postural control system and assess sway. Despite this, no standardised measurement protocol has been established to measure sway. Therefore many discrepancies exist regarding feet and arm position, trial number and length and the numerous COP parameters derived from the force plate data (Era et al., 1996).

### **6.1 The Number and Length of Trials Necessary to Achieve Reliability**

Recent literature states the frequently used 10-30 second test duration is not sufficient to attain reliable results in some COP parameters (Doyle, Hsiao-Wecksler, Ragan, & Rosengren, 2007; Santos et al., 2008). Earlier research by Le Clair & Riach (1996) suggested that optimal test-retest reliability is obtained in a trial of between 20 to 30 seconds but dependant upon the outcome measures being observed. The 20 to 30 second timeframe is based on the suggestion that with time, alternating standing strategies are adopted to maintain stance which could explain the increased variability seen with increased trial length (Le Clair & Riach, 1996). It is postulated by Le Clair & Riach (1996), that at the beginning of a trial, the subject may start to sway around a *home base* and as time progresses and the body moves more, several *home bases* may be adopted. As a new *home base* is developed, the position of the COP moves to ensure upright stance can be maintained but also increases the variability of the COP position leading to increased sway over time. Conversely, a study by Lafond et al (2004) found little difference in intra-class coefficient (ICC) values between trials lasting 60 and 120 seconds suggesting that an extra 60 seconds is unnecessary to achieve good reliability. ICC is a measure of reliability (used in this study and others) that can be interpreted as poor (0.2-0.4), moderate (0.4-0.6), good (0.6-0.8) and excellent (0.8-1) although each study varies slightly (Mientjes & Frank, 1999). Other indices include coefficient of variation or % standard error of the mean (SEM) which show the capacity to detect change over time (Santos et al., 2008). Lafond et al (2004) also found that ICC values plateau after 4 trials of 60 to 120 seconds, deeming further trials unnecessary (Lafond et al., 2004). Le Clair & Riach's study highlighted that due

to the diversity among COP parameters measured and the methods used to obtain data, only trials of the same duration and outcome measures can truly be compared (1996).

## **6.2 COP Parameters**

Results of studies have shown intra- and inter-session reliability varies between different COP parameters. (Lin et al., 2008). Literature regarding inter-session reliability is scarce therefore the following claims are based on intra-session results. Current research suggests COP velocity to be the most consistently reliable of sway measures between studies while sway area has found to be the least reliable (Lafond et al., 2004). A study conducted by Doyle et al. (2007) found moderate reliability values for confidence ellipse area and COP velocity (Santos et al., 2008). Although Lafond et al. (2004) and Lin et al. (2008) used a similar participant group and the same testing conditions, Lin et al (2008) obtained greater reliability in all COP parameters including mean sway velocity, sway area and root mean square distance. This was possibly due to a different statistical model used by Lin et al (2008) to obtain mean square terms in ICC calculations. Bauer et al, (2008) included the influence of visual input on the reliability of measuring sway and found better reliability in trials with closed eyes rather than open. All COP parameters included in Bauer's study (mean area, length, medial/lateral and anterior/posterior sway) obtained good to excellent reliability (Bauer et al., 2008).

## **6.3 Influence of Visual Information on Postural Stability and Reliability of Measurement**

As discussed previously, the control of upright stance is dependent upon the integration of afferent information from the visual, vestibular and somatosensory systems. When a system is individually eliminated, an affect is measurable and unable to be completely compensated for (Simoneau et al., 1995). A study by Simoneau et al. (1995) concentrated on the hierarchical organization of the three systems as well as the extent of compensatory abilities of the remaining systems when one is impaired or eliminated. To do this, each system was removed individually, before combinations of systems then all three systems involved in postural control. Results showed the system to have the most dramatic effect on postural control as measured by percentage displacement of the COP to be an impaired somatosensory system with a

66% increase in COP movement. In order to achieve this, the study used patients with diabetic neuropathy, which decreases the amount and quality of proprioceptive feedback from the peripheral nerves of the feet. The second most influential system to postural control was vision with a 41% increase in COP movement following its removal (Simoneau et al., 1995). This study also highlighted the importance of independent contributions from all three systems by the inability of the remaining systems to compensate completely for the removal or impairment of any one system (Simoneau et al., 1995).

Physical and physiological visual parameters have been shown to affect postural control during upright stance. These parameters include visual acuity, visual contrast, lighting, optical blur, central and peripheral visual fields, static or dynamic visual cues (Pinsault & Vuillerme, 2009). This is not ideal when aiming to establish reliable and useable clinical tests. Interestingly, previous studies have found measuring sway with eyes-closed to be more reliable than when sway is measured with eyes-open (Bauer et al., 2008; Hadian et al., 2008). This may be indicative of the difficulty controlling the number intrinsic and extrinsic variables of visual input on postural stability therefore decreasing eyes-open reliability of measurement. In order to help control the intrinsic variables of visual input, subjects would need visual testing prior to a study to ensure equal visual capacities between subjects and the physical testing environment used in the study would need standardising in terms of light, point of focus and any possible peripheral distractions. In the absence of visual impairment, it has been shown that the visual system works best at a distance of less than two metres (Kejonen, 2002). With this in mind, it may be reasonable to assume the elderly or visually impaired individuals to have decreased postural control and therefore possibly more susceptible to falls and instability.

More recent literature has contradicted the conclusions of Simoneau et al. (1995) by suggesting that the availability of visual information is enough for the postural control system to compensate for postural deficits (Pinsault & Vuillerme, 2009). Thus, the removal of visual input is necessary when evaluating postural control as it aids in the discrimination between healthy subjects and those with sensory (visual, vestibular, proprioceptive, sensory-motor) impairment (Pinsault & Vuillerme, 2009). This reduces the use of an eyes open condition as a normative based clinical protocol for objective evaluation of postural control, particularly if the somatosensory or vestibular systems are likely to also be impaired (Pinsault & Vuillerme, 2009).

#### **6.4 Intra-session Versus Inter-session Reliability**

Research in the field of reliability of postural control has to this point been mostly concerned with intra-session reliability (Bauer et al., 2008; Corriveau et al., 2000; Lafond et al., 2004; Pinsault & Vuillerme, 2009). The few studies that have considered both intra- and inter-session reliability have not surprisingly found intra-session reliability to be superior to inter-session reliability (Lin et al., 2008). A study by Benvenuti, Mecacci, Gineprari et al. 1999 used ICC values to assess the reliability of several COP -based measures at four-hour and one-week intervals (Lafond et al., 2004; Lin et al., 2008). Results indicated better reliability of COP measures when taken at four-hour intervals than when compared to one-week intervals consistent with previous results indicating better intra-session than intersession reliability (Lin et al., 2008).

### **7. THE RELEVANCE OF POSTURAL STABILITY RESEARCH TO MANUAL THERAPY**

The effectiveness of manual therapy can be difficult to objectively quantify as practitioner assessment, patient feedback and clinical progress are all subjective in nature (Jones, 1992). Postural stability is a necessary and essential factor in the performance of even simple daily activities that improve quality of life. It could also be an important indicator of health as postural stability is known to be compromised by numerous factors e.g. chronic pain and injury as well as the effects of more subtle lifestyle choices (Deliagina et al., 2007). Obtaining a method that reliably and objectively measure postural stability allows the contribution sway measurements to the body of manual therapy research. Until recently, the incidence, social and medical impact of falls has been the major impetus for research into postural stability (Lafond et al., 2004). However, as chronic pain has been shown to impair postural control (Dehner et al., 2008; Mientjes & Frank, 1999; Nies & Sinnott, 1991), sway could be utilised as objective measure of an individual's diagnosis, recovery and their short- and long-term response to treatment. Recent research into the effectiveness of osteopathic manipulative treatment has found significant reductions of pain intensity in individuals with chronic low back pain when compared to controls (Kirk, Underwood, Chappell, Martins-Mendez, & Thomas, 2005; Licciardone et al., 2003) However, these benefits were measured using subjective patient reports pain e.g.

disability questionnaires. Claims made by the osteopathic profession regarding the benefits of manipulative treatment to chronic back pain could be verified through measuring objectively postural sway before and after osteopathic intervention. Obtaining positive results from this and consequent inter-session reliability studies is the first step of achieving this goal.

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## **SECTION TWO**

*Manuscript*

## 1. INTRODUCTION

Postural stability is a necessary and essential aspect in the performance of even simple daily activities that improve quality of life. An interruption to any of the mechanisms responsible for controlling posture can bring about a sense of instability, vulnerability particularly for the elderly, as well as predispose falls and further injury (Bauer et al., 2008; Lafond et al., 2004; Lin et al., 2008). Numerous factors including; age, sensory disorders, life-style factors and pathology can adversely affect postural sway (Demura et al., 2005; Hadian et al., 2008; Lafond et al., 2004; Lin et al., 2008; Mientjes & Frank, 1999; Mizrahi et al., 2006; Mok et al., 2004; Nies & Sinnott, 1991; Nieschalk et al., 1999; Nosaka, 2002; Overstall et al., 1977). These factors alter the ability of the body's control system to adapt to changing stimuli thus increasing both postural sway and the energy expenditure necessary to maintain upright stance (Alexander & LaPier, 1998). Postural sway refers to the oscillation of the body's centre of mass over ones base of support which occurs as the result of muscular activity counteracting the internal and external perturbations acting on the body (Alexander & LaPier, 1998). Sway can be measured using a force plate, which measures the trajectory of the centre of pressure (COP) over a period of time.

From a force plate, postural sway can be represented by several parameters (Kuukkanen, 2000) each with varying degrees of reliability reported in previous research (Lafond, 2004). The COP parameters used in this study are *Average Speed (medial/lateral & anterior/posterior)*, *Length of COP path*, *Area of COP path* and *RMSa*, chosen based on their common use and positive results in previous research (Bauer et al., 2008; Hadian et al., 2008; Lafond et al., 2004; Lin et al., 2008; Pinsault & Vuillerme, 2009). Although the force plate is a common method used to assess postural sway, there is currently no agreed standardised method that reliably assesses postural stability using this equipment.

The objectives of this study were to (1) determine the intra- and inter-session reliability of COP -based measures of postural stability of a normal population and (2) establish a standardised protocol easily repeatable at a tertiary teaching and research facility. A carefully selected amalgamation of previously pursued protocols was used to design the standardised method used in this study (Bauer et al., 2008; Doyle et al., 2007; Hufschmidt, 1980; Lafond et al., 2004; Le Clair & Riach, 1996; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996; Santos et al., 2008). All testing was

completed in eyes open and eyes closed conditions to investigate the influence of vision on the reliability of postural stability measurements (Santos, 2008).

Additionally, this study investigates the relationship between subjective pain intensity and anthropometric characteristics and postural stability in this sample population. There is evidence that chronic low back and neck pain (Dehner, 2008; (della Volpe et al., 2006; Demura et al., 2005; Hamaoui et al., 2004; Harringe et al., 2008; Leitner et al.; Mientjes & Frank, 1999; Nies & Sinnott, 1991; Radebold et al., 2001) and other anthropometric characteristics have a significant effect on postural stability (Kejonen et al., 2003). In this study subjective pain intensity, age, gender, height, shoe size and body mass index were recorded in this study in order to observe their possible influence on postural stability.

## 2. METHODS

### Subjects

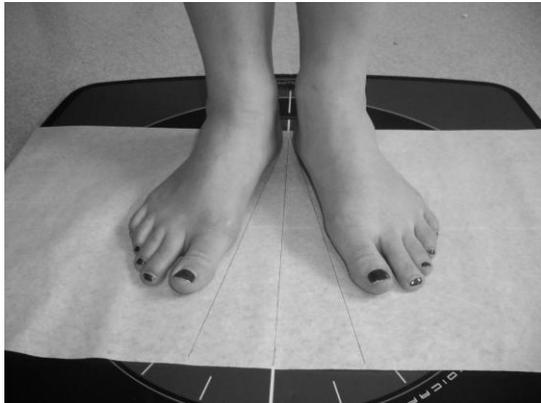
The study's participant sample consisted of 34 healthy subjects (19 females: mean age  $25\pm 4$ , 15 males: mean age  $29\pm 7$ , age range 19-42 years) who each volunteered for this study. All subjects were able to stand unassisted for two minutes. No further restrictions were placed on participation criteria as the sample was aimed to be representative of a normal population. Subjects were recruited through the use of Facebook advertisements, word of mouth and posters placed throughout Unitec, Mt Albert and local stores, health centres and cafes.

COP trajectory was recorded using a Medicapteurs *S-Plate* over three sessions performed throughout a four-week period. Each trial was comprised of six 75-second tests. Subjects were scheduled at 30-minute intervals dependant on their availability and advised to choose a time that could be kept for four consequent weeks. Upon arrival, all subjects read an information sheet (Appendix A) and were given the opportunity to ask questions before signing a consent form (Appendix A). Subjects were given the option to withdraw from the study up to two weeks post data collection with no consequences.

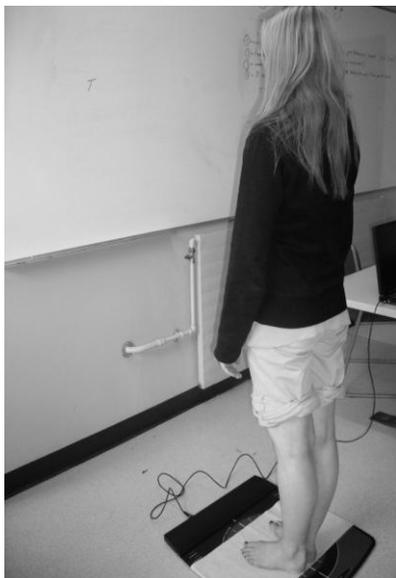
### Stances

Subjects were required to perform all tests without footwear. For hygiene purposes, subjects were permitted to wear socks if they chose and a disposable template was laid over the *S-Plate* force platform and changed regularly. Subjects were instructed to stand as naturally as possible looking straight ahead with their head erect and arms resting at their sides. Each trial consisted of six tests. This involved three consecutive tests with eyes-open looking at a point equivalent to eye-level along a vertical line marked 90cm in front of them and three tests maintaining the standardised position but with eyes closed. The order visual conditions were performed was selected at random during week one and maintained throughout the remaining trials for each subject. Subjects were instructed to open their eyes between tests. To ensure consistency between tests, a standardised testing position was designed incorporating aspects of previous methods (Bauer et al., 2008; Pinsault &

Vuillerme, 2009) involving participants to stand with their heels at a distance of 2cm and a foot angle (medial border) of 30° (Figures 1, 2).



**Figure 1.**  
*Feet aligned on template at 30° on the S-plate.*



**Figure 2.**  
*Subject X in testing position*

## **Procedure**

Height and weight were measured and recorded on each subject's anonymized questionnaire (Appendix B). Subjects were required to complete the questionnaire each week prior to testing. The questionnaire included three main sections: anthropometric characteristics; lifestyle factors including cigarette, caffeine and alcohol intake, hours of sleep; and subjective pain characteristics including the duration, site, troublesomeness and pain intensity as indicated by visual analogue scale (VAS).

Subjects stepped onto and stood quietly and as naturally as possible on a Mediateurs *S-Plate* force platform for six successive tests with a 20 second rest period between tests. A longer rest period of two minutes was given following the third test where conditions altered to either eyes open or eyes closed. Subjects were encouraged to remain in the standardised position between testing however they did have the option to walk around or step off the force plate if wished. The total testing duration of 75 seconds included 10 seconds to find the position and settle, 60 seconds of data collection, followed by 5 seconds to allow for any anticipatory movement nearing test completion.

This procedure was repeated over three sessions held on weeks one, two and four. Week three was missed due to unavailability of many participants due to a local public holiday. Participants were strongly urged to maintain the same time and day of testing for consistency.

## **Apparatus**

Postural sway as represented by trajectory of the COP was recorded using the Mediateurs *S-Plate* platform and associated *S-Plate* software, version 1.36. COP data from the *S-Plate* platform were sampled at a frequency of 100Hz and input into the Mediateurs computer software. This set-up resulted in the acquisition of 300 individual data points and images for each COP parameter over a 60 second collection period. A disposable template was placed over the S-Plate with a 30° angle marked for consistency of foot positioning (Figure. 3).



**Figure 3.**  
*The S-Plate with template marking the 30° angle for standardised foot positioning*

## Data Analysis

All statistical analysis was conducted using the *xrely* (<http://www.sportsci.org/resource/stats/>) spreadsheet provided by Hopkins, 2009. Based on positive outcomes of previous literature (Bauer et al., 2008; Lafond et al., 2004) and the capabilities of the *S-plate* platform and software, the COP parameters analysed were *Length of COP path*, *Average Speed (in two directions; anterior/posterior and medial/lateral)*, *Area of COP path* and *Root Mean Square area (RMSa)*. Data were log-transformed prior to analyses to negate the effects of heteroscedasticity. In cases where the data value was 'zero' (RMSa values), 0.5 was added to the score prior to analyses (Bradburn, Decks, Berlin, & Localio, 2007; Rucker, Schwarzer, Carpenter, & Olkin, 2009; Sweeting, Sutton, & Lambert, 2004).

The reliability of each COP parameter was quantified using intra-class correlation coefficient (ICC) and the typical percent error: the standard error of a measurement expressed as a coefficient of variation (Hopkins, Schabert, & Hawley, 2001). An ICC is the most commonly used index to report relative reliability (Hadian et al., 2008) and is used to differentiate between participants giving an indication of the diagnostic value of a measure (Santos et al., 2008). Hopkins (2009) states that an ICC value of 0.9-1 should be used as a threshold indicating validity [or reliability]. Magnitudes of effect were interpreted according to the criteria of Cohen (1988) & Hopkins (2009) as shown in Table 1 and interpreted using 90% confidence intervals.

**TABLE 1**  
**Interpretation of ICC values in terms of magnitude of effect (Hopkins, 2009)**

<b>Correlation Coefficient</b>	<b>Descriptor</b>
0.0-0.1	trivial, very small, insubstantial, tiny, practically zero
0.1-0.3	small, low, minor
0.3-0.5	moderate, medium
0.5-0.7	large, high, major
0.7-0.9	very large, very high, huge
0.9-1	nearly, practically, or almost: perfect, distinct, infinite

In order to compare weeks for inter-session reliability, the raw data of each week in each parameter and condition were averaged leaving one value representative of that subject. Thus, 34 values were available for analysis for each week in each condition and parameter. The *xrely* spreadsheet was then utilised for reliability

analysis using 102 averaged values for one parameter which compared week one, two and three in both visual conditions.

### 3. RESULTS

Thirty-four subjects (19 females: mean age  $25\pm 4$ , 15 males: mean age  $29\pm 7$ , age range 19-42 years) were recruited in order to test the intra- and inter-session reliability of COP -based measures using a standardised method with a Medicauteurs *S-plate* force platform. All subjects met ethical requirements for the study (Appendix A) and were able to stand unassisted for at least two minutes. No further restrictions or participation criteria were used as the sample was aimed to represent as best as possible, a normal population.

The standardised method used in this study was derived from previous literature (Bauer et al., 2008; Doyle et al., 2007; Hufschmidt, 1980; Lafond et al., 2004; Le Clair & Riach, 1996; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996; Santos et al., 2008) and involved having each subject stand barefoot on the *S-plate* force platform for 75 seconds. This procedure was repeated six times each session on three different weeks.

#### **Intra-session Reliability of COP Parameters**

All five COP parameters used in this study showed Moderate to Very Large correlations. CV, ICC values and CI's for each outcome parameter are presented in Tables 2-7. To establish intra-session reliability, a total of twelve ICC's were calculated for each parameter across two visual conditions. Because subjects completed three trials in each condition, two ICC values were calculated for each COP parameter each week. There were no dropouts throughout this study therefore all data sets are complete.

#### ***Average Speed (Medial/Lateral)***

*Average Speed (M/L)* was the most consistently reliable COP parameter in all trials, obtaining Very Large ICC values ranging from 0.75 to 0.9 (Table 2). With the exception of one measure, this parameter resulted in a 90% CI with an upper limit of 0.9 or above while the lower limit ranged from 0.59 to 0.77. These ICC's had the narrowest spread of all parameters studied. The CVs for this parameter ranged from 17 to 22% in both conditions (eyes open and eyes closed).

**TABLE 2**  
*Average Speed (Medial/Lateral) across the three trials*

<b>Condition</b>	<b>Week</b>	<b>Mean CV(%)</b>	<b>CI*</b>		<b>ICC</b>	<b>CI*</b>		<b>ICC Value°</b>
			<b>Upp</b>	<b>Low</b>		<b>Upp</b>	<b>Low</b>	
Eyes Open	1	19	17	23	0.87 to 0.87	0.77	0.92	Very Large
	2	22	19	26	0.75 to 0.82	0.59	0.90	Very Large
	3	17	15	20	0.81 to 0.81	0.68	0.92	Very Large
Eyes Closed	1	22	19	26	0.76 to 0.90	0.60	0.95	Very Large
	2	19	16	22	0.86 to 0.87	0.76	0.92	Very Large
	3	22	19	26	0.77 to 0.80	0.61	0.89	Very Large

Notes: CV = coefficient of variation; CI = confidence interval; ICC = intra-class correlation coefficient.

\* denotes 90% confidence interval (Upp = upper; Low = lower); ° denotes interpretation value of ICC.

***Length of COP path and Average Speed (Anterior/Posterior)***

*Length of COP path* and *Average Speed (A/P)* also proved reliable in this study having Large to Very Large correlation values across all trials in both conditions (Table 3 & 4). *Length of COP path* demonstrated five of six outcomes to have a Very Large correlation while the remaining measure obtained a Large correlation. The range of ICC values for *Length of COP path* ranged from 0.66 to 0.88 (Table 3). *Average Speed (A/P)* ICC values were slightly lower ranging from 0.62 to 0.85 (Table 4). The spread of ICC values was larger for *Length of COP path* and *Average Speed (A/P)* parameters than *Average Speed (M/L)* with 90% CI ranges of 0.46 to 0.93 and 0.41 to 0.91 respectively. Both COP parameters obtained CV values of from 18 to 24% across both conditions.

**TABLE 3**  
*Length of COP Path across the three trials*

<b>Condition</b>	<b>Week</b>	<b>Mean CV(%)</b>	<b>CI*</b>		<b>ICC</b>	<b>CI*</b>		<b>ICC Value°</b>
			<b>Upp</b>	<b>Low</b>		<b>Upp</b>	<b>Low</b>	
Eyes Open	1	20	24	17	0.86 to 0.87	0.93	0.77	Very Large
	2	24	28	21	0.66 to 0.84	0.91	0.46	Large
	3	18	22	16	0.79 to 0.88	0.93	0.65	Very Large
Eyes Closed	1	21	25	18	0.74 to 0.88	0.93	0.57	Very Large
	2	19	23	17	0.84 to 0.86	0.92	0.73	Very Large
	3	21	25	18	0.76 to 0.80	0.88	0.60	Very Large

Notes: CV = coefficient of variation; CI = confidence interval; ICC = intra-class correlation coefficient.

\* denotes 90% confidence interval (Upp = upper; Low = lower); ° denotes interpretation value of ICC.

**TABLE 4**  
*Average Speed (Anterior/Posterior) of COP Path across the three trials*

<b>Condition</b>	<b>Week</b>	<b>Mean CV(%)</b>	<b>CI*</b>		<b>ICC</b>	<b>CI*</b>		<b>ICC Value°</b>
			<b>Upp</b>	<b>Low</b>		<b>Upp</b>	<b>Low</b>	
Eyes Open	1	21	25	18	0.81 to 0.85	0.91	0.68	<i>Very Large</i>
	2	24	28	20	0.62 to 0.81	0.89	0.41	<i>Large</i>
	3	19	22	16	0.77 to 0.82	0.90	0.62	<i>Very Large</i>
Eyes Closed	1	22	26	19	0.69 to 0.79	0.88	0.50	<i>Large</i>
	2	22	26	19	0.79 to 0.81	0.89	0.64	<i>Very Large</i>
	3	22	26	19	0.71 to 0.75	0.86	0.53	<i>Large</i>

*Notes:* CV = coefficient of variation; CI = confidence interval; ICC = intra-class correlation coefficient.

\* denotes 90% confidence interval (Upp = upper; Low = lower); ° denotes interpretation value of ICC.

***Area of COP path and Root Mean Square area (RMSa)***

*Area of COP path* and *RMSa* were the least reliable intra-session COP parameters of this study. In the same testing conditions, these parameters resulted in Moderate to Very Large correlation (Table 5 & 6). The 90% CI's of ICC values for the *Area of COP path* showed the largest spread of all parameters, in one trial ranging from 0.16 to 0.80. The pattern of CV values was supportive of the magnitude of the ICC value excluding *Area of COP path* and *RMSa* parameters. *Area of COP path* also had the largest CV values (48% to 72%), more than double that of the remaining COP parameters while *RMSa* showed the lowest CV values of all parameters but ICC values fell primarily within a Moderate range and 90% CI's spread from 0.08 to 0.86.

**TABLE 5**  
*Area of COP path across the three trials*

<b>Condition</b>	<b>Week</b>	<b>Mean CV(%)</b>	<b>CI*</b>		<b>ICC</b>	<b>CI*</b>		<b>ICC Value°</b>
			<b>Upp</b>	<b>Low</b>		<b>Upp</b>	<b>Low</b>	
Eyes Open	1	57	70	49	0.75 to 0.79	0.88	0.60	<i>Very Large</i>
	2	72	88	61	0.43 to 0.67	0.80	0.16	<i>Moderate</i>
	3	54	66	46	0.56 to 0.77	0.86	0.32	<i>Large</i>
Eyes Closed	1	51	62	44	0.54 to 0.80	0.88	0.30	<i>Large</i>
	2	49	59	42	0.70 to 0.78	0.87	0.51	<i>Large</i>
	3	48	58	41	0.61 to 0.68	0.81	0.39	<i>Large</i>

*Notes:* CV = coefficient of variation; CI = confidence interval; ICC = intra-class correlation coefficient.

\* denotes 90% confidence interval (Upp = upper; Low = lower); ° denotes interpretation value of ICC.

**TABLE 6**  
*Root Mean Square (area) across the three trials*

<b>Condition</b>	<b>Week</b>	<b>Mean CV(%)</b>	<b>CI*</b>		<b>ICC</b>	<b>CI*</b>		<b>ICC Value<sup>o</sup></b>
			<b>Upp</b>	<b>Low</b>		<b>Upp</b>	<b>Low</b>	
Eyes Open	1	16	19	14	0.68 to 0.76	0.86	0.49	<i>Large</i>
	2	18	21	15	0.41 to 0.46	0.66	0.14	<i>Moderate</i>
	3	17	20	14	0.38 to 0.56	0.73	0.11	<i>Moderate</i>
Eyes Closed	1	16	19	14	0.36 to 0.67	0.80	0.08	<i>Moderate</i>
	2	19	23	17	0.58 to 0.68	0.81	0.35	<i>Large</i>
	3	16	19	14	0.42 to 0.52	0.70	0.15	<i>Moderate</i>

*Notes:* CV = coefficient of variation; CI = confidence interval; ICC = intra-class correlation coefficient.

\* denotes 90% confidence interval (Upp = upper; Low = lower); <sup>o</sup> denotes interpretation value of ICC.

### **Inter-Session Reliability of COP Parameters**

In order to analyse inter-session reliability, the mean values were calculated for each COP parameter in each condition for each week. As with intra-session reliability, CV, ICC values and 90% CI's were calculated for each outcome parameter. Overall, intra-session ICC values were almost always higher when compared to each parameter's inter-session equivalents.

### ***Average Speed (M/L, A/P) and Length of COP path***

*Average Speed (M/L & A/P) and Length of COP path* were the most reliable parameters obtaining Very Large ICC values in both conditions (Table 7). The CV values of these three parameters followed a similar trend to that seen within sessions ranging from 17% to 22%. ICC values obtained under eyes closed conditions were consistently higher in all three parameters than with eyes open. CV's were also consistently lower in this condition.

### ***Area of COP path and Root Mean Square area (RMSa)***

*Area of COP path* obtained Large correlation values of 0.66-0.75 and 0.71-0.72 in each condition respectively (Table 7). The CV values of the *Area of COP path* parameter were more than double that of others at 45 and 40% for eyes open and eyes closed conditions respectively. *RMSa* was the least reliable parameter with variable correlation values ranging from 0.27 to 0.73 (Small to Large correlation). Within its 90% CI limit, the lower value with eyes open dropped into negative digits, -0.01 to

0.84 (Table 7). However, *RMSa* obtained CV values of 16 and 17% were the lowest of all parameters.

**TABLE 7**  
Each COP parameter between all three weeks

COP Parameter	Visual Condition	Mean CV(%)	CI*			CI*		
			Upp	Low	ICC	Upp	Low	ICC Value
AvgSpd(ML)	EO	22	26	19	0.74 to 0.76	0.86	0.58	Very Large
	EC	18	22	16	0.83 to 0.85	0.92	0.72	Very Large
AvgSpd(AP)	EO	20	24	17	0.73 to 0.82	0.90	0.56	Very Large
	EC	17	20	15	0.79 to 0.86	0.92	0.65	Very Large
Length of path	EO	22	26	19	0.71 to 0.86	0.92	0.53	Very Large
	EC	19	22	16	0.77 to 0.87	0.93	0.61	Very Large
Area of path	EO	45	55	39-	0.66 to 0.75	0.85	0.46	Large
	EC	40	48	34	0.71 to 0.72	0.83	0.53	Large
<i>RMSa</i>	EO	16	19	14	0.27 to 0.73	0.84	-0.01	Small-Large
	EC	17	21	15	0.38 to 0.57	0.74	0.11	Moderate

Notes: CV = coefficient of variation; CI = confidence interval; ICC = intra-class correlation coefficient.

\* denotes 90% confidence interval (Upp = upper; Low = lower); ° denotes interpretation value of ICC. EO = eyes open. EC= eyes closed

### The Effect of Visual Input on the Reliability of Measuring Postural Stability

The effect of visual input was more apparent within inter-session data than intra-session. In order to observe and compare the effect of vision on intra and inter-session reliability, the mean ICC's have been calculated and summarised in Table 8. The addition or removal of visual stimulus did not appear to conclusively affect the intra-session reliability results of this study however a difference was observed between visual conditions between sessions.

**TABLE 8**  
Intra-session and Inter-session reliability of each COP parameter for each condition (eyes open, eyes closed)

COP Parameters	Intra-session		Inter-session	
	Eyes Open	Eyes Closed	Eyes Open	Eyes Closed
Average Speed (M/L)	0.81 to 0.83	0.80 to 0.86	0.74 to 0.76	0.83 to 0.85
Average Speed (A/P)	0.73 to 0.83	0.73 to 0.78	0.73 to 0.82	0.79 to 0.86
Length of COP path	0.77 to 0.86	0.78 to 0.85	0.71 to 0.86	0.77 to 0.87
Area of COP path	0.58 to 0.74	0.62 to 0.75	0.66 to 0.75	0.71 to 0.72
<i>RMSa</i>	0.49 to 0.59	0.45 to 0.62	0.27 to 0.73	0.38 to 0.57

Note: Data are mean ICC values

### ***The effect of visual input on intra-session reliability***

Minimal difference is seen between visual conditions throughout all COP parameters within sessions (Table 2-6, 8). ICC values remained reasonably constant between visual conditions. Both conditions showed large to very large correlation values for *Average Speed (A/P & M/L)* and *Length of COP path*. *Area of COP path* had the highest CV values and the widest spread of ICC values ranging from moderate to very large ICC values of both conditions. *Length of COP path* was the only parameter to obtain higher ICC values with eyes closed than eyes open within a session. *Area of COP path* and *RMSa* remained the least reliable of the five COP parameters in both conditions.

### ***The effect of visual input on inter-session reliability***

All COP parameters showed consistently higher ICC values when eyes were closed between sessions. CV values were 3 to 4% lower under eyes closed conditions than with eyes open. The difference was not large enough to alter the interpretation of ICC values therefore, *Average Speed (M/L & A/P)*, *Length of COP path* and *Area of COP path* all presented with Very large and Large correlation in both conditions. ICC values were less consistent between visual conditions between sessions when compared to within sessions (Table 7 and 8).

### **The Relationship between Postural Stability and Subjective Pain Intensity**

In order to investigate the magnitude of the relationship between subjective pain intensity and/or anthropometric characteristics to postural stability, subjects completed a questionnaire before each session including personal details such as age, height, weight, shoe size and a visual analogue scale (VAS) (Appendix B). On the VAS scale, subjects ranked their pain level from zero (no pain) to 10 (worst pain). *Length of COP path* was chosen for further analysis using comparative graphs (Figures 4a,b-9a,b). This parameter was chosen as it was among the top three most reliable measures of intra and inter-session reliability. These scatter plots showing the relationship between *Length of COP path* and VAS scores in both eyes open and eyes closed conditions are shown in Figure 4a and 4b.

No obvious relationship can be seen between subjective pain intensity (VAS) and postural stability (Figure 4a, 4b). Of the asymptomatic subjects, data points are

widely spread from approximately 25 to 200mm under eyes open conditions (Figure 4a). With eyes closed, asymptomatic subjects had a path length ranging from approximately 50 to 250mm (Figure 4b). Data points of those experiencing pain were evenly spread across Length of COP path values. The majority of data fell between a path length of 50 and 150mm and below a VAS score of four. No relationship can be seen between the highest VAS score and the greatest Length of COP path.

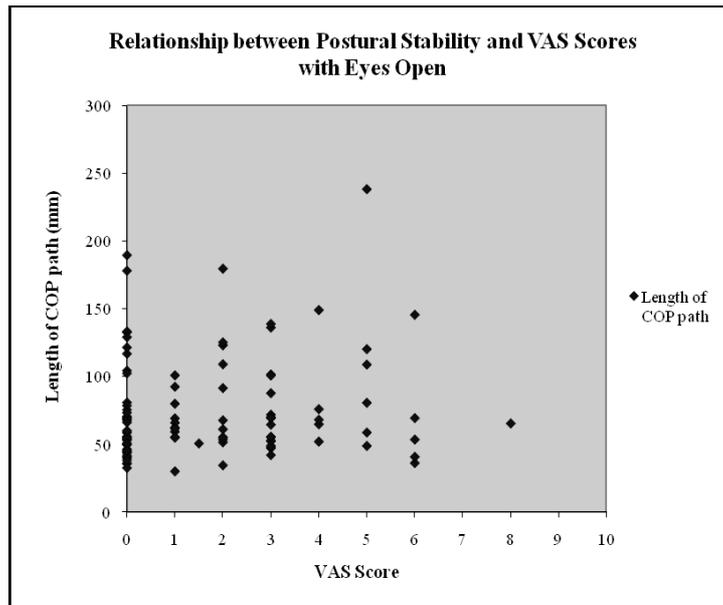


Figure 4a. Illustration of the relationship between Postural Stability as represented by *Length of COP path* and pain using visual analogue scale (VAS) scores with eyes open

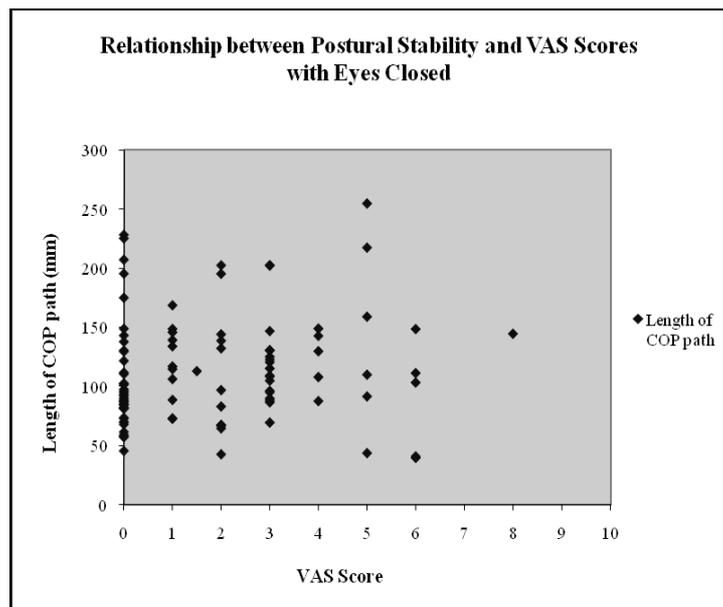


Figure 4b. Illustration of the relationship between Postural Stability as represented by *Length of COP path* and pain using visual analogue scale (VAS) scores with eyes closed

### **The Relationship between Postural Stability and Anthropometric Characteristics**

For continuity of relationships to postural stability, *Length of COP path* was the parameter used for comparison in each of the following graphs. Scatter plots illustrate relationships between postural stability and age (*Figure 5a, 5b*), height (*Figure 6a, 6b*), shoe size (*Figure 7a, 7b*), gender (*Figure 8a, 8b*) and body mass index (*Figure 9a, 9b*) and are shown below for eyes open and eyes closed conditions.

The data points in each chart showed great variability with no defined linearity or trends. No apparent relationships between age, height, shoe size or body mass index and postural stability can be observed within this study. A notable difference was seen between genders. Female subjects showed greater postural sway than male subjects. The female group contained the individual with the greatest sway and overall a greater group average of sway. Females also had a large degree of spread, highlighted by this group obtaining the highest and lowest sway measurements of all subjects. The addition or removal of visual stimulus did not appear to influence these findings.

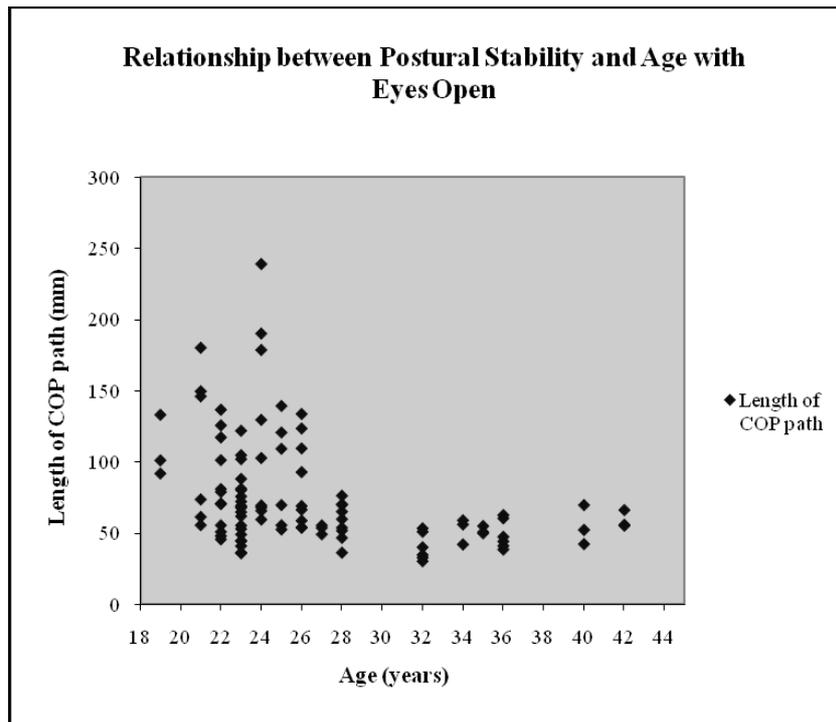


Figure 5a. Illustration of the relationship between subject age and postural stability as represented by Length of COP path with eyes open

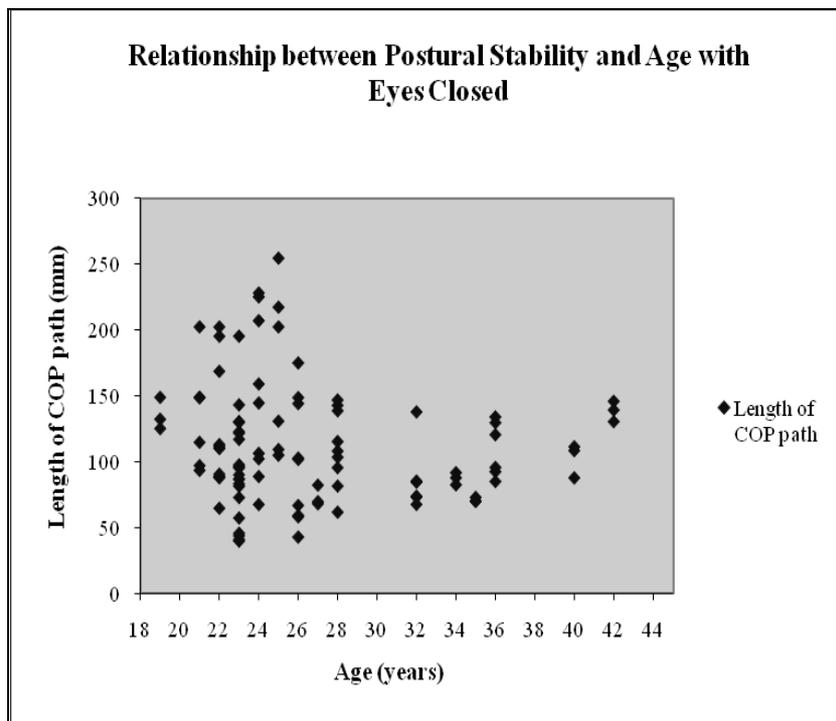


Figure 5b. Illustration of the relationship between subject age and postural stability as represented by Length of COP path with eyes closed

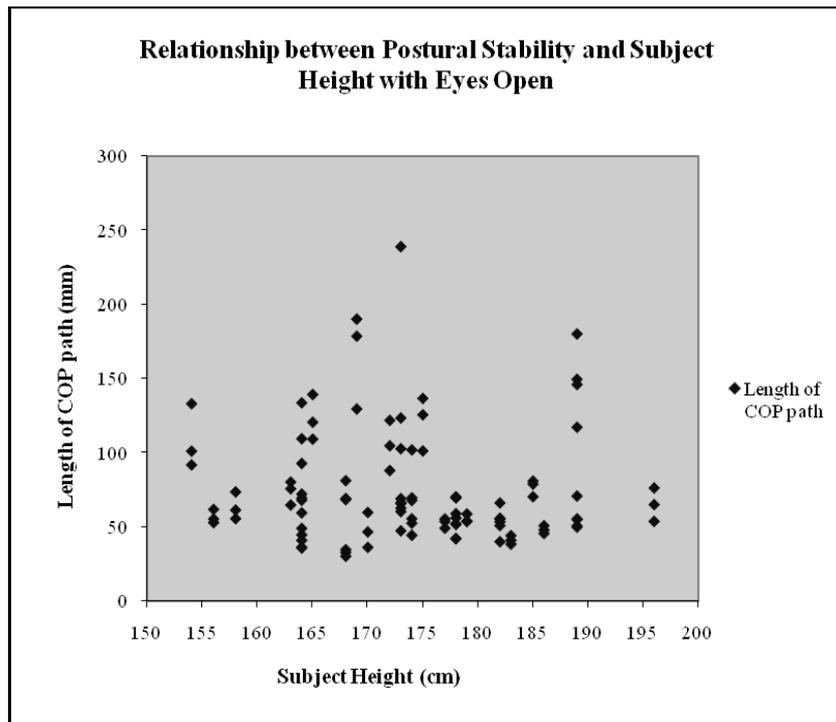


Figure 6a. Illustration of the relationship between subject height (metres) and postural stability as represented by *Length of COP path* with eyes open

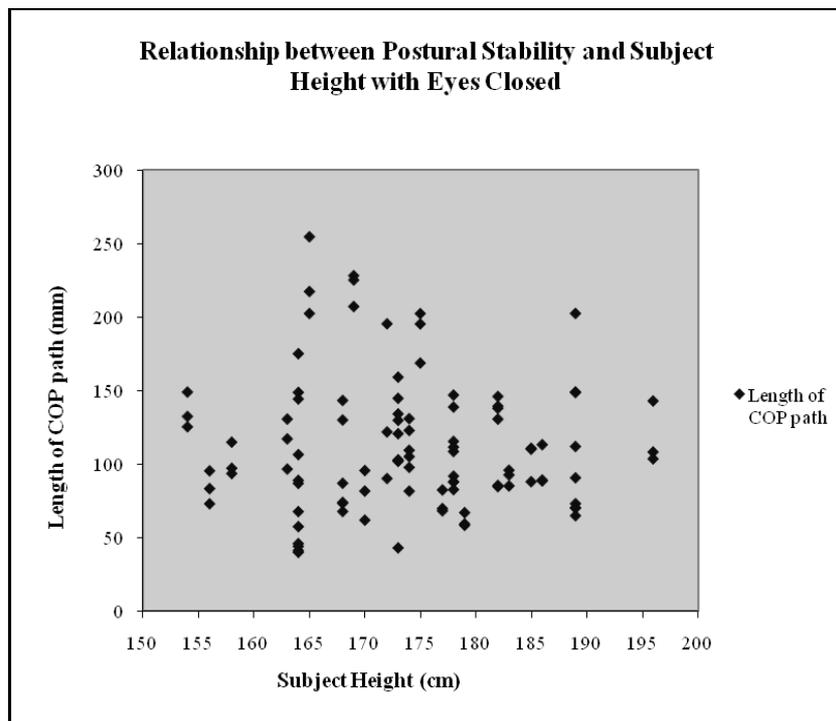


Figure 6b. Illustration of the relationship between subject height and postural stability as represented by *Length of COP path* with eyes closed

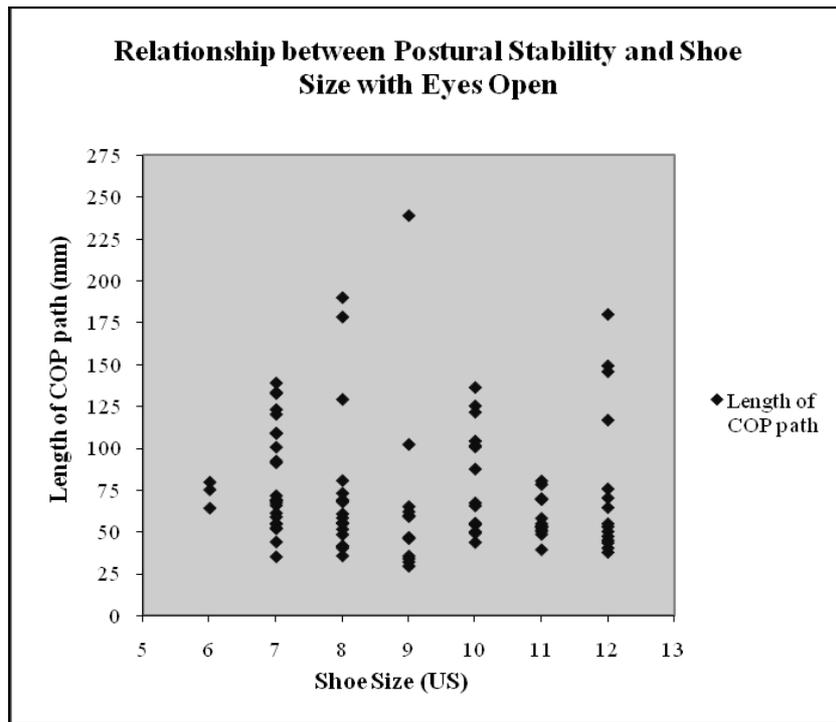


Figure 7a. Illustration of the relationship between shoe size and postural stability as represented by Length of COP path with eyes open

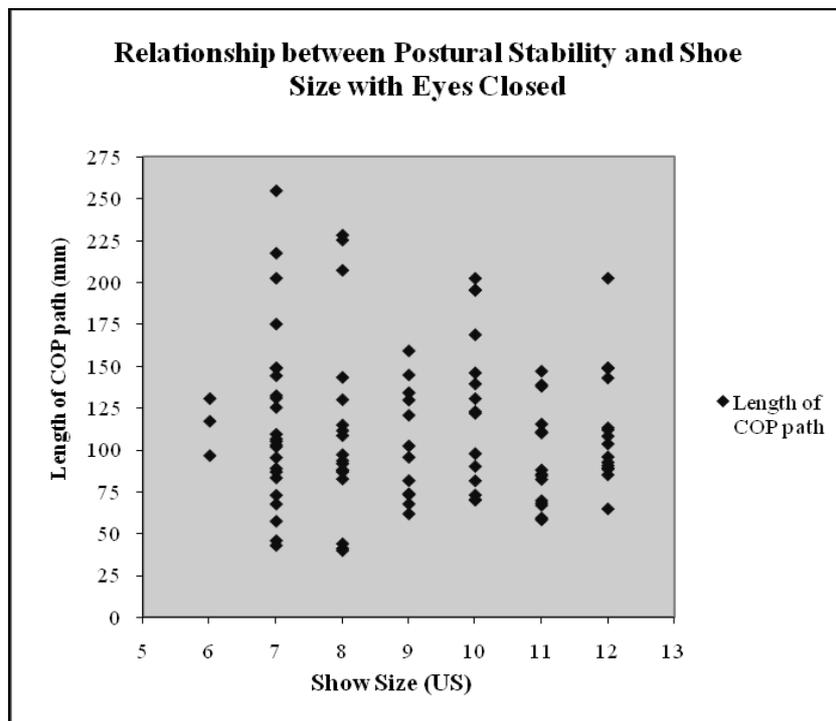


Figure 7b. Illustration of the relationship between shoe size (US) and postural stability as represented by Length of COP path with eyes closed

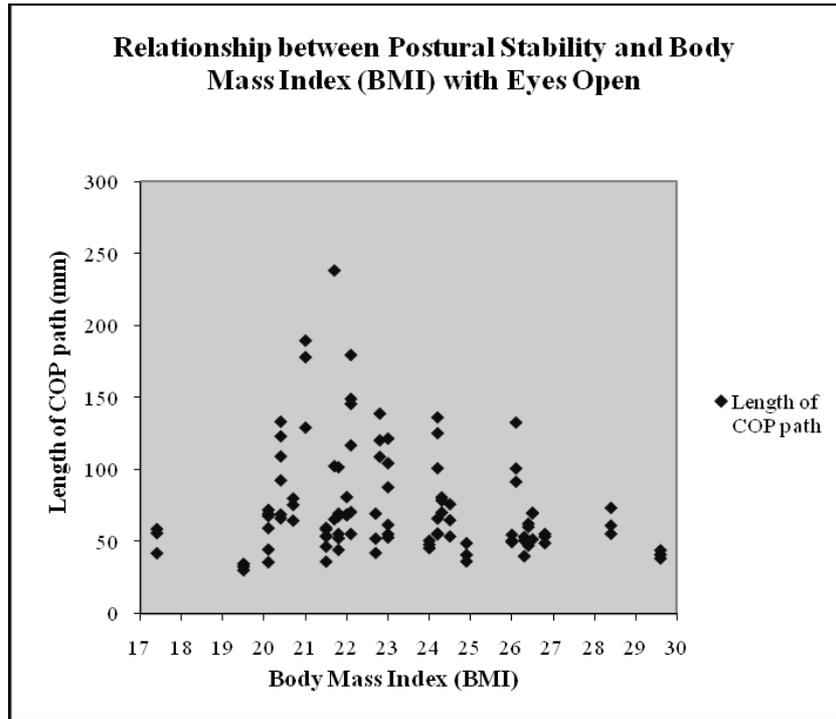


Figure 8a. Illustration of the relationship between subject body mass index (BMI) and postural stability as represented by *Length of COP path* with eyes open

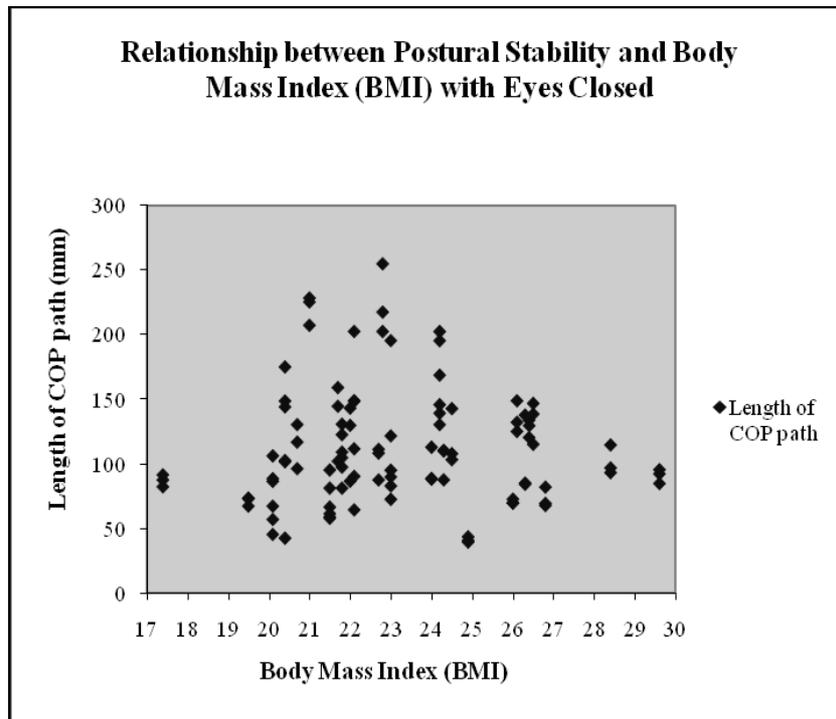


Figure 8b. Illustration of the relationship between body mass index (BMI) and postural stability as represented by *Length of COP path* with eyes closed

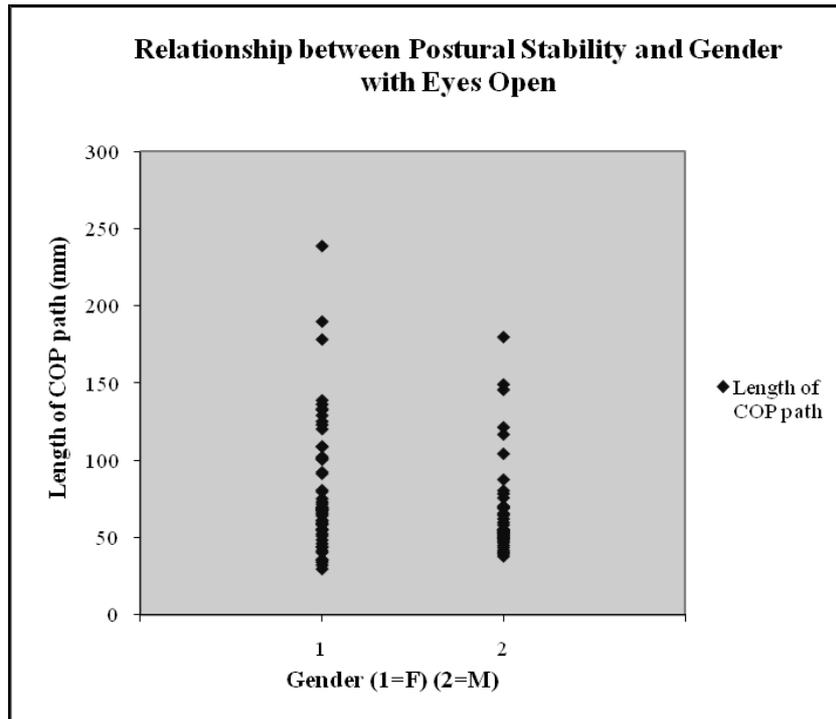


Figure 9a. Illustration of the relationship between subject gender and postural stability as represented by Length of COP path with eyes open

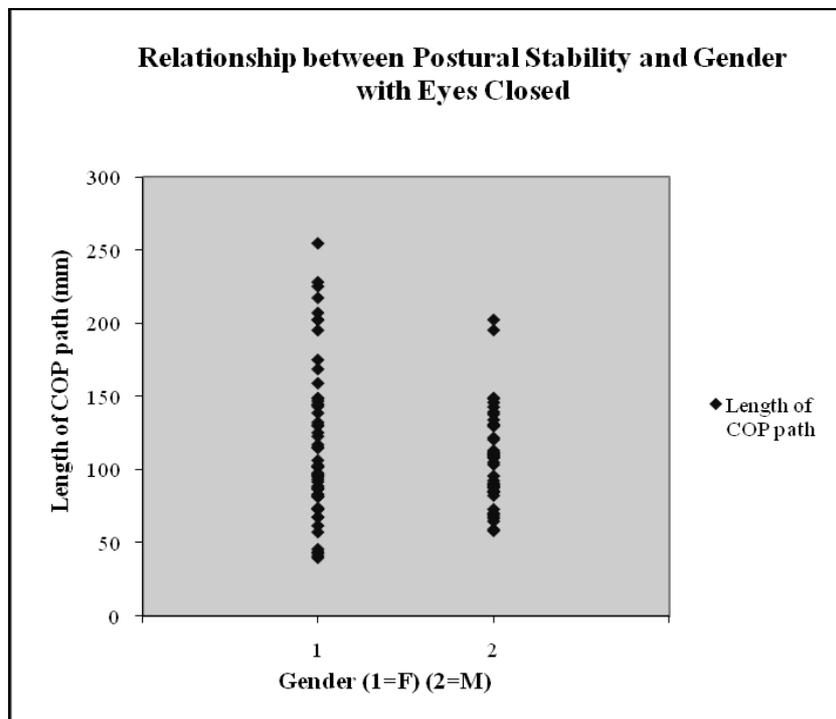


Figure 9b. Illustration of the relationship between subject gender and postural stability as represented by Length of COP path with eyes closed

#### 4. DISCUSSION

Postural control refers to the body's ability to maintain the equilibrium of its centre of mass over the base of support during upright stance, sitting and voluntary movements (Harringe, Halvorsen, Renstrom, & Werner, 2008). In order to achieve this, the body utilises several sensory modalities; visual, vestibular and proprioceptive which feedback to specific co-coordinated motor output from many joints simultaneously to counteract the constant destabilising forces acting upon it (Harringe et al., 2008; Mientjes & Frank, 1999; Radebold, Cholewicki, Polzhofer, & Greene, 2001; Schumann, Redfern, Furman, El-Jaroudi, & Chaparro, 1995). Postural control is mostly an unconscious function requiring little attention until it becomes compromised usually as a result of injury, aging or pathology (Schumann et al., 1995). The interruption of balance can bring about a sense of instability, vulnerability and a predisposition to falls. This is particularly relevant for the elderly population (Bauer, Groger, Rupprecht, & Gabmann, 2008; Lafond, Corriveau, Hebert, & Prince, 2004; Lin, Seol, Nussbaum, & Madigan, 2008). Postural control can be assessed using a force plate which measures the trajectory of the COP within ones base of support over a period of time (Bauer et al., 2008; Pinsault & Vuillerme, 2009). However, the method of its use in research needs standardisation in order to be able to compare different studies (Bauer et al., 2008; Doyle, Hsiao-Wecksler, Ragan, & Rosengren, 2007; Hufschmidt, 1980; Lafond et al., 2004; Le Clair & Riach, 1996; Lin et al., 2008; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996; Santos, Delisle, Lariviere, Plamondon, & Imbeau, 2008).

The main objectives of this study were to determine the intra- and inter-session reliability of (COP) -based measures of postural control in normal subjects and to establish a standardised method using the Medicapteurs *S-Plate* force platform that can easily be repeated at a tertiary teaching facility. Although some reliability studies have been conducted that aim to reduce the variability of results when measuring postural control, the optimal number and length of trials, subject positioning and the best COP parameters used are yet to be agreed upon (Claydon & Hainsworth, 2005; Corriveau, Hebert, Prince, & Raiche, 2000; Cornwall & Murrell, 1991; Davidson, Madigan, & Nussbaum, 2004; Demura, Kitabayashi, Kimura, & Matsuzawa, 2005; Hadian et al., 2008; Hamaoui, Do, & Bouisset, 2004; Harringe et al., 2008; Kuukkanen & Malkia, 2000; Lafond et al., 2004; Le Clair & Riach, 1996;

Lin et al., 2008; Marvel, Schwartz, & Rosse, 2003; Mientjes & Frank, 1999; Salavati et al., 2009; Samson & Crowe, 1996; Santos et al., 2008). Therefore, due to the variation seen between the methods used and the COP parameters employed it is difficult to truly compared previous studies (Bauer et al., 2008; Lafond et al., 2004; Lin et al., 2008; Salavati et al., 2009; Samson & Crowe, 1996; Santos et al., 2008; Le Clair & Riach, 1996). In the current study, the Medicauteurs *S-Plate* force platform was used to determine reliability of measuring postural stability using a protocol based on aspects from previous studies (Bauer et al., 2008; Doyle et al., 2007; Hufschmidt, 1980; Lafond et al., 2004; Le Clair & Riach, 1996; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996; Santos et al., 2008).

### **Intra-session versus Inter-session Reliability**

Overall, the study's results indicated varying intra- and inter-session reliability between different COP parameters consistent with previous literature (Lin et al., 2008). Not surprisingly, intra-session reliability showed marginally superior to inter-session reliability in the majority of the COP parameters studied. The few studies (Lafond et al., 2004; Lin et al., 2008) that have considered both intra- and inter-session reliability have reached conclusions consistent with this study. A study by Benvenuti, Mecacci, Gineprari et al. (1999) utilised ICC values to assess the reliability of measuring several COP -based measures at four hour and weekly intervals (Lafond et al., 2004; Lin et al., 2008). They found ICC values obtained at four hour intervals were significantly greater than those taken weekly suggesting intra-session measures to be more reliable than inter-session measures (Lin et al., 2008). Work by Lin et al (2008) supported that of Benvenuti et al, when comparing the intra- to inter-session reliability of COP -based measures. With greater ICC values, within day reliability was superior to between day reliability (Lin et al., 2008). The present study obtained intra-session values at two to three minute intervals while inter-session values were taken one week and consequently two weeks apart (due to participant availability). Findings of this study were consistent with those of previous studies: intra-session reliability in this study was found to be slightly superior to inter-session reliability in four of the five COP parameters measured. Because no data was obtained from multiple sessions of the same length interval during this study, it is difficult to draw conclusions regarding the influence of interval length between testing. However, from these studies it is reasonable to assume that very good inter-

session reliability can be obtained for the *Average Speed (M/L & A/P)* and *Length of COP path* parameters when measured at an interval of up to two weeks apart.

Lin et al. (2008) proposed that lower inter-session compared to intra-session reliability could be due to a change in postural control over different days, as they found a significant multivariate day effect. They suggest that there may be long-term postural control adaptation occurring between consecutive test days suggesting the development of a motor memory pattern over this time period. However, it would seem more likely for postural control to improve over time rather than deteriorate as is noted by Lin et al, (2008) and in the current study. A long-term postural control adaptation involving the development of a motor-programmed task would have a similar effect to a subject undergoing balance practice or training regimes, again suggesting an improvement in postural control more likely. Not surprisingly, Lin's theory was dismissed as no obvious trends were seen after numerous testing sessions and instead a yet to be identified random effect between days was suggested to be responsible for decreased inter-session reliability (Lin et al., 2008). It is reasonable to assume that inter-session reliability when compared to intra-session reliability is influenced by variables that are less controllable.

The results of this study agree with those of Lin et al. (2008), in that no trends were observed throughout the repeated sessions. Therefore, any influence of a practice effect was at best minimal. Because many methodological variables were standardised in this study, it is less likely that the method was a cause of lower inter-session reliability. However, the method used in this study was limited in one respect. Although, all subjects were asked to remove shoes for testing, whether they stood barefoot or wearing socks was optional. Whatever the decided footwear, it was maintained throughout the session, but not between subjects or between consequent sessions. This should have been standardised to eliminate any possibility of influence to proprioceptive feedback from the feet. However, it is also important to acknowledge the static nature of testing used for this study and that foot placement was established before data collection began, thus making the impact of this discrepancy arguably negligible. Excluding this error, other variable factors were controlled as much as possible. The same examiner conducted all trials eliminating any possibility of inter-examiner variation. The method of data collection was consistent between trials, as were the subjects testing days and time unless unforeseen circumstances arose. Because these aspects were controlled, yet inter-session

measures remained less reliable than intra-session, it suggests biological error such as uncontrollable stresses of daily living or inconsistency of postural control mechanisms between days to be at least partially responsible for any increased variation observed between sessions. In order to achieve excellent inter-session reliability further research is necessary to identify stressors or events prior to testing that may impact stability.

The magnitude of intra- and inter-session reliability varied dependant on the COP parameter being measured consistent with Lin et al., (2008). The current study was potential limited by assessing all five COP parameters simultaneously using three trials of 75-second duration. In order to obtain better intra- and inter-session reliability it may be useful to separate all COP parameters to allow for individualised testing. For example, using a different number or length of trials individualised to the COP parameter being assessed. This could help to identify an optimal number and duration of trials to achieve excellent reliability specific for each COP parameter.

### **Reliability of COP Parameters**

This study found *Average Speed (M/L & A/P)* and *Length of COP path* to be the most reliable intra- and inter-session COP parameters in both visual conditions. These findings were consistent with previous research that states COP velocity to be the most consistently reliable of sway measures between studies (Lafond et al., 2004) *Area of COP path* was less reliable than *Average Speed* and *Length of COP path* but still showed reasonable relative intra- and inter-session reliability as indicated by Large ICC values but low absolute reliability with poor CV% in both visual conditions. *RMSa* showed poor reliability independent of interval between trials or visual information.

The rationale behind choosing the five COP parameters used in this study was based on their common use in reliability studies and the results obtained in these studies (Bauer et al., 2008; Hadian et al., 2008; Lafond et al., 2004; Lin et al., 2008; Pinsault & Vuillerme, 2009). The purpose of this study was to assess the reliability of COP parameters using the protocol described and to compare the reliability outcomes obtained from this method to other studies (Bauer et al., 2008; Hadian et al., 2008; Lafond et al., 2004; Lin et al., 2008; Pinsault & Vuillerme, 2009) with the eventual aim of designing a standardised protocol allowing comparison among studies. Therefore, it was important for the COP parameters being measured to be consistent

with previous literature however this was partially limited by the capabilities of the Mediacpteurs *S-Plate* and software.

Among the COP parameters studied, *Average Speed (M/L)* was the most reliable within and between sessions irrespective of visual stimuli. Under the current testing procedure, this parameter obtained Very Large correlation within sessions and between sessions. Supporting this were CVs ranging between 17-22% consistent with work by Hadian et al, (2008) who found average velocity to be the most reliable parameter with a CV of 20.4% and an ICC of 0.89. All but one measure for this parameter resulted in a 90% CI ranging from Large to Excellent correlation (0.59->0.9).

*Length of COP path* and *Average Speed (A/P)* followed a similar trend with Large to Very Large correlation within and between sessions also irrespective of visual input. The spread of ICC values was greater for *Length of COP path* and *Average Speed (A/P)* parameters than *Average Speed (M/L)* with 90% CI ranges of 0.46-0.93 and 0.41-0.91 respectively. Supporting this was a slight elevation of CV values for both parameters ranging between 18-24% indicative of the broader spread of data. *Average speed (A/P)* was the lower of the three most reliable COP parameters shown by comparatively lower ICC values. Consistent with intra-session data of the current study, *Average Speed (M/L & A/P)* and *Length of COP path* were the most reliable COP parameters between sessions having consistently Very Large correlation in both visual conditions. CV values of these three parameters ranged from 18% to 22% consistent with intra-session results and previous research (Hadian et al., 2008).

*Area of COP path* and *RMSa* were the least reliable COP parameters within and between sessions. In the same testing conditions, both parameters indicated mediocre reliability highlighted by variable ICC values ranging from Moderate to Very Large correlation. In this study, one trial consisted of three identical tests in eyes open and eyes closed conditions therefore the lower ICC values are indicative of variation between these tests still within intra-session reliability. These findings are consistent with previous literature stating area of COP path commonly falls short of proving a reliable COP parameter when assessing postural stability (Hadian et al., 2008; Lafond et al., 2004; Santos et al., 2008). Not surprisingly, *Area of COP path* also had by far the largest CV values, more than double that of the other four parameters studied reflecting large variability within a single test. Similar CV values of 49.3% in the eyes closed condition were seen in a study by Hadian et al., (2008)

compared to the 48-51% in the same condition of the present study. Furthermore, the 90% CI's of ICC values for *Area of COP path* showed the largest spread of all parameters, in one trial ranging from 0.16 to 0.80. *Area of COP path* and *RMSa* continued a similar trend between sessions with large 90% CI's highlighting the diverse variation between ICC values. The CVs of both eyes open and eyes closed conditions for *Area of COP path* were slightly lower at 45% and 40% respectively.

Interestingly, *RMSa* showed the lowest CV values of all COP parameters but the least reliable ICC values. This is possible because although ICC and CV are both measures of reliability, they are not directly related. The CV values are of importance as they are indicative of the variation of a measure in relation to its mean; therefore *RMSa* had little variance about the mean within a single test. However, this consistency was not observed when multiple tests were compared as variance increased dramatically. The inter-test and inter-session variance is represented by ICC values, which measure homogeneity between pairs or sets of data (McGraw, 1996). ICC values for the *RMSa* parameter were primarily of Moderate correlation although values ranged from 0.08-0.86.

While three of the studied COP parameters obtained values that can be interpreted as Large to Very Large correlation, it is important to highlight that within these limits are values of only Moderate correlation but also Excellent correlation, particularly within the *Length of COP path* and *Average Speed (A/P)* parameters. However, because the majority of ICC values fell within the Large to Very large correlation brackets, all three COP parameters (*Average Speed M/L & A/P* and *Length of COP path*) can be considered very reliable measures of postural stability. In comparison with previous literature, although no identical studies have been conducted, ICC values have shown similar figures and trends in respect to the different COP parameters of previous studies which have stated good to excellent intra-session reliability (Lafond et al., 2004; Pinsault & Vuillerme, 2009). The information gained from this study regarding the magnitude of intra- and inter-session reliability of each of the COP parameters studied can be used as a foundation for future research to elaborate on including the implementation of controlled variables and interventions.

### **Influence of Visual input on Reliability of Measuring of Postural Stability**

The importance of visual input for postural stability has been documented in previous studies (Kejonen, 2002; Pinsault & Vuillerme, 2009; Redfern, 2001; Simoneau, Ulbrecht, Deri, & Cavanagh, 1995). The influence of visual information on postural stability was highlighted by Simoneau et al, showing a 41% increase in COP displacement when visual input was removed (1995). It has been shown (Pinsault & Vuillerme, 2009) that in the presence of visual information, the postural control system is able to compensate for other sensory deficits. However, due to the sensitivity of the visual system to a number of variables including visual acuity, optical blur, contrast sensitivity, visual motion cues and central or peripheral visual fields, assessing postural stability with eyes open raises the opportunity for variation between subjects (Pinsault & Vuillerme, 2009). This is not ideal when aiming to establish reliable and useable clinical tests. Visually deprived conditions are also necessary when evaluating postural control as testing in the absence of visual input can aid in the discrimination between healthy subjects and those with sensory (visual, vestibular, proprioceptive) or sensory-motor impairment (Pinsault & Vuillerme, 2009). Interestingly, measuring sway with eyes-closed has been shown to be more reliable than when sway is measured with eyes-open (Bauer et al., 2008; Hadian et al., 2008).

This study was also interested in investigating the influence of vision on the reliability of measuring postural sway within a normal population. Results showed that the effect of visual information on reliability is more apparent between sessions than within them. Overall, inter-session reliability with eyes closed was greater for all five COP parameters when compared to within session values. However, this was not enough to alter the interpretation of data in that the three most reliable parameters (*Average Speed M/L & A/P and Length of COP path*) showed consistently Very Large correlation values in both visual conditions. Reflecting the Very Large correlation values were four of the five COP parameters obtaining considerably lower CV values (3-4%) in eyes-closed conditions when compared to eyes-open figures. Together, these results suggest a high magnitude of absolute and relative inter-session reliability for the *Average Speed (M/L & A/P)* and *Length of COP path* parameters particularly when visual input is eliminated. Visual deprivation as described earlier, is a necessary factor when evaluating postural control as it aids in differentiating healthy subjects from those with sensory or sensory-motor impairments (Simoneau et al., 1995). As

subjects in this study performed equally if not more consistently under visually deprived conditions, one could predict that of the 34 subjects included in this study, none were suffering from any unknown significant vestibular or proprioceptive deficits. Although inter-session reliability was overall greater in visually deprived conditions, intra-session values showed less discrepancy when comparing the two conditions. Therefore, it appears from this study that inter-session reliability is more sensitive to visual conditions than within a session. This conclusion was consistent with Bauer et al. (2008) and Hadian et al. (2008).

The visual systems role in postural control is primarily focused towards planning locomotion and the avoidance of obstacles (Winter, 1995). It seems plausible that in static stance, the vestibular and somatosensory systems would play a larger role due to their functions of sensing the body's linear or angular accelerations and monitoring the position, orientation and velocity of each body segment and the segment's contact with external objects (Winter, 1995). As testing was performed in static conditions, visual cues would seem less necessary than during dynamic tasks, thus highlighting the responsibilities of each sensory system during upright stance. The importance of visual input during static stance in individuals with no sensory deficits may then be arguable as the visual information could provide opportunity for visual distraction or disturbance during the 60-second test period. This could explain why eyes closed conditions appear more reliable in this study. Furthermore from this study, as all subjects reported to be healthy and with no serious visual, vestibular or proprioceptive deficit, it indicates that the loss of visual input can be completely compensated for by the remaining sensory systems highlighted by the lack of variance found within and between sessions. These results may indicate a redundancy of the visual system during 60-seconds of unperturbed stance for postural stability.

In this study, the order in which subjects underwent each visual condition was randomised during the first trial and stayed consistent for that subject throughout successive trials. However the effect of order was not accounted for further in this study as data would need to be divided and analysed according to the order subjects performed each visual condition resulting in a reduced overall sample size. In light of this, no conclusions regarding the impact of order of visual condition (whether it eyes open before eyes closed for vice versa) can be drawn. This could be investigated in future research to establish if there is an effect of order on reliability of measuring

postural sway. For instance, it is plausible that there could be a short-term (same day) training effect when a subject is immediately measured within short timeframe.

### **Reasoning Behind the Chosen Protocol for this Study**

The force plate has the potential to be a reasonably reliable means of calculating and assessing COP trajectory, however the method of its use in research varies considerably (Lafond et al., 2004). To date there is no accepted standardised method of reliably assessing postural stability on a force plate. Studies use varying protocols regarding; subject head, arm and/or feet positioning, footwear, trial length (ranging from 8 seconds to 3 minutes with majority at 30 seconds), and the chosen COP parameters (Bauer et al., 2008; Corriveau et al., 2000; Hadian et al., 2008; Lafond et al., 2004; Le Clair & Riach, 1996; Lin et al., 2008; Pinsault & Vuillerme, 2009; Salavati et al., 2009; Samson & Crowe 1996; Santos et al., 2008). With still so much methodological variation between studies, previous research provides a reasonably weak foundation to base additional research upon.

This study employs an amalgamation of aspects from previous methods and procedures in order to reliably evaluate postural stability and establish a standard protocol for future studies (Bauer et al., 2008; Doyle et al., 2007; Hufschmidt, Dichgans, Mauritz, Hufschmidt, 1980; Lafond et al., 2004; Le Clair & Riach, 1996; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996; Santos et al., 2008). Therefore, it is the first study to be conducted using this specific method with aim to test the intra- and inter-session reliability of *Average Speed (M/L & A/P)*, *Length of COP path*, *Area of COP path* and *RMSa* within a normal population. This internalised standardised method involved consistency of the examiner, number and length of trials, testing equipment, testing environment and positioning of the subject within and between sessions. However, it is difficult to compare this to other studies as only identical studies can truly be compared (Le Clair & Riach, 1996). Until a standardised method is used between research groups this will remain problematic.

Foot placement can be and has been used as a variable to assess its influence on sway (Lafond et al., 2004). Studies have been conducted with the feet placed in numerous conditions including; feet together, tandem (one foot in front of the other), feet apart and parallel, feet at pelvic width apart or at a 30 degree foot angle (Bauer et al., 2008; Lafond et al., 2004; Lin et al., 2008; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996; Winter, 1995). The commonly adopted 30-degree foot angle was

chosen for this study due to its ease of standardisation ensuring subject continuity between tests, sessions and each other (Bauer et al., 2008; Pinsault & Vuillerme, 2009). However, many subjects involved in the current study reported that they felt unnatural and that this position is difficult to maintain. This seemed particularly relevant for some body types. Alternately, a feet together stance, similar to that used by Samson & Crowe, (1996) may have felt more natural for some subjects and improved postural sway however keeping in mind this stance does minimise the base of support which may also jeopardise stability. The relevance of different stances need to be addressed in future studies as this could be important to establish the validity of any protocol for measuring postural stability. A study that allows subjects to stand in a position natural to them may be necessary in order to assess validity of measuring postural sway, however due to variation of foot positioning, the reliability of measurement would be questionable in such a study.

The influence of attention to task on postural sway has been highlighted in previous research (Olivier, Palluel, & Nougier, 2008). This is an extremely difficult variable to control for both the examiner and subject. In order to overcome this issue, subjects would need to be blinded to the purpose and aims of the study raising potential ethical participation issues. Therefore, possible subject attention to task was not accounted for in this study.

The number of trials needed per study to achieve Very Large or Excellent ICC values has for years been an area of disputation between studies (Hufschmidt et al., 1980; Lafond et al., 2004; Pinsault & Vuillerme, 2009; Samson & Crowe, 1996). Samson & Crowe, (1996) stated a minimum of 10 trials necessary for intra-session consistency of COP velocity and path length measures based on the coefficient of variation (CV). Also using CV to assess reliability, Hufschmidt et al found intra-subject variation of the COP parameter; sway area, to have a high CV of 58.9% after 10 trials (1980) indicative of poor absolute reliability. The CV values obtained from the current study were consistent with results of Hufschmidt et al., (1980) for the sway area parameter despite only three trials being performed. Studies by Pinsault & Vuillerme (2009) and Lafond et al. (2004) used ICC values as the measure of reliability and found results to contrast those of Hufschmidt et al, (1980), Samson & Crowe, (1996) by demonstrating that of the 10 trials performed, only three were necessary in order to establish an ICC value over 0.75 or excellent reliability. In light of this more recent research, it was decided that three trials of 60 seconds would be

used for the current study and obtained similar results to both of the latter studies (Lafond, 2004; Pinsault & Vuillerme, 2009). Furthermore, three trials were chosen as it was thought that too many trials might jeopardise subject participation compliance as well as allow the possibility for a fatigue or practice effect to influence results.

The trial length of the current study was 75 seconds. This was comprised of 60 seconds of data collection, 10 seconds prior to testing to allow each subject to ensure correct foot placement and settle before testing and 5 seconds post-data collection to limit anticipatory deviation caused by stepping off the force plate. The chosen trial length was based on a study by Lafond et al (2004) that found little difference in the magnitude of reliability obtained from trials lasting 60 or 120 seconds. Both resulted in ICC values of above 0.8 deeming an extra 60 seconds unnecessary to achieve good reliability. Furthermore, recent literature states the frequently used 10-30 second duration is not sufficient to attain reliable results in some COP parameters (Doyle et al., 2007; Santos et al., 2008). Earlier research by Hufschmidt et al, (1980) proposed that longer trials, greater than 60 seconds, may help to decrease the high variability of COP measures responsible for decreasing the clinical significance of the study. However, more recent literature has continued to provide evidence rejecting this claim (Le Clair & Riach, 1996; Lafond, 2004; Doyle, 2007; Santos, 2008).

### **Data Analysis**

Within this and other reliability studies, the method and data analysis used are as important as the results obtained. In this study, data analysis included; intra-class correlation coefficient (ICC), 90% CI of ICC values and coefficient of variation (CV) as each show a slightly different aspect of reliability. ICC is the most commonly chosen measure to report relative reliability and determined as the ratio of variance between subjects to the total variance (Lin et al., 2008; Santos et al., 2008). The use of the 90% CI shows how closely measurements agree over different trials, while CV demonstrates the precision of measurements. It is important to note that the results of a reliability study are only as good as the interpretation criteria used to decipher them. The method of data analysis and the interpretation criteria used has varied between studies and therefore, care must be taken as the results of one study can only truly be compared to others using the same criteria (Le Clair & Riach, 1996).

Previous research shows a variety of criteria have been established and used to interpret ICC values (Hadian et al., 2008; Lafond et al., 2004; Lin et al., 2008;

Mientjes & Frank, 1999; Pinsault & Vuillerme, 2009). The current study used criteria outlined by Cohen 1988 and Hopkins 2008 (see Methods). The ICC value needed to establish reliability or clinical acceptability varies within literature. ICC values of 0.8, 0.85 and above have been stated by some researchers as sufficient to establish excellent reliability (Lafond et al., 2004). In addition, studies that used the Fleiss classification regard any ICC value equal to or above 0.75 as an indication of excellent reliability and to be clinically acceptable (Hopkins, 2000; Lin et al., 2008; Pinsault & Vuillerme, 2009). Using this classification, three of the five COP parameters employed (Average Speed (M/L & A/P) and Length of COP path) in this study showed excellent reliability and are clinically acceptable. However, when the results of this study are interpreted using the criteria outlined by Cohen 1988, and Hopkins 2008, these three COP parameters obtained ICC values of Very Large correlation (0.7-0.9) but Hopkins states an ICC value of 0.9-1 (perfect) is necessary for absolute validity [or reliability] of a measure (Hopkins, 2009). According to this stringent criteria, none of the current study's COP parameters could conclusively be considered a valid or reliable measure of postural sway. Although, *Average Speed* and *Length of COP path* parameters obtained an upper 90% CI limit of 0.9 or above.

Coefficient of Variation (CV) is a common measure of reliability for elite sports performance in which case values are ideally around 2% (Hopkins, 2009), whereas lab studies can remain valid with a CV of up to 20% (Reed, 2002). In this study, CVs were interpreted using literature by Hopkins, 2009 and Hadian et al, 2008 that states one can concur good reliability with CV values of approximately 20%. Using this interpretation, the results of this study show good reliability as four of the five COP parameters obtained CV's of  $20 \pm 4\%$ .

In a reliability study, the possibility of systematic bias must be considered (Hadian et al., 2008). Hadian et al. (2008) state "a systematic bias is a non-random change in the values between two trials whereby all participants perform consistently better in one trial resulting from learning or fatigue effects" (p.3032). The present study indicated no systematic bias, therefore the protocol can be assumed to not cause of fatigue or learning effects on postural stability (Hadian et al., 2008).

## **Postural Stability and Pain**

Many factors have been studied and proven to have a significant effect on postural sway including chronic neck (Dehner et al., 2008) and low back pain (della Volpe et al., 2006; Demura et al., 2005; Hamaoui et al., 2004; Harringe et al., 2008; Leitner et al.; Mientjes & Frank, 1999; Nies & Sinnott, 1991; Radebold et al., 2001). Following the reliability study where the COP parameter *Length of COP path* showed Very Large intra- and inter-session reliability in both visual conditions, it was chosen for further analysis correlating pain intensity to postural stability. Although this study used a subject participation criterion that would select a normal healthy population, any normal healthy population will have individual variation and subtle differences in perceived levels of health and pain. This analysis could help design future research to establish the extent to which pain and other factors influence postural sway.

In order to investigate possible correlation between pain intensity and postural stability VAS scores were compared to the COP parameter (*Length of COP path*) representing postural sway. VAS was chosen as it is simple to use and one of the best-known methods to estimate pain intensity (Carlsson, 1983). From this study, no relationship can be made between the pain intensity reported by this normal population and postural stability. Within this 'normal' population there were varying degrees of pain within and between individuals. The site of pain was not taken into account for this study. If a subject had multiple sites of pain with varying VAS scores, the highest score was utilised for analysis. This was a weakness in this study. An individual suffering pain in multiple sites may feel more debilitated than an individual with severe pain in only one area. Furthermore, should the pain be felt solely in a remote area, such as a finger or wrist, this would seem unlikely to affect the mechanisms functioning to achieve postural control unless it was the psychological aspect of pain influencing stability.

Although this study does not show any relationship between pain intensity and postural stability, previous studies have found that chronic pain can significantly influence stability. The duration or location of pain rather than pain intensity may be an important aspect to its influence. The aetiology behind pain's influence on postural stability is thought to be due to lack of proprioceptive input from the spinal musculature and ligamentous structures due to facilitation of the nervous system (Mok, Brauer, & Hodges, 2004; Radebold et al., 2001). With this in mind, chronicity of pain is possibly more likely to be an influential factor, as facilitation would

increase over time lowering or confusing proprioceptive feedback. The pain duration of subjects in this study varied from less than one day to 12 weeks or longer.

A potential limitation of this study was the sample population consisting largely of healthy although not completely asymptomatic Unitec osteopathic students. Therefore, the sample was not truly representative of a normal population. Thus, these reliability results cannot be generalised to all populations, such as the elderly or individuals with compromising conditions to postural control (Lin et al., 2008).

### **Postural Stability and Anthropometric Characteristics**

Regind, Lykkegaard, Bliddal, Danneskiold-Samsee, (2003) evaluated the effect of various lifestyle, demographic and anthropometric factors in 195 normal 20-70 year olds. Their study indicates that of the seven factors studied (age, weight, height, body mass index, alcohol and cigarette consumption and articular hypermobility), only two factors influenced postural stability. These factors were increased age (increased sway with increased age) and gender (females swayed less than males).

The current study looked at similar anthropometric characteristics to those of Regind et al, (2003) including age, height, gender and, body mass index (BMI) but also included shoe size. The sample population had a mean age of 27 years and ranged from 19 to 42 years. The subjects with the greatest sway as measured by *Length of COP path*, fell at ages 24 and 25 in the eyes open and eyes closed conditions respectively. These points were considerably higher than those of the older but also younger subjects. The majority of research into the effect of age on postural stability has used subjects of at least 60 years and found there to be increased sway in these individuals when compared with younger controls (Bauer et al., 2008; Lafond et al., 2004; Lin et al., 2008). As the oldest subject in this study was only 42 years old, the effect of aging was not apparent.

Interestingly, the results of this study regarding the influence of gender differed from that of Regind et al, (2003). Female subjects of the current study gave an impression of greater postural sway than the males, contradicting previous work (Regind et al, 2003). The female group generated both the individual with the greatest sway and when outliers were disregarded, the upper limits of the group remained higher than that of the male group, particularly when eyes were open. Under eyes closed conditions, the female group data was widely spread represented by the female group obtaining the highest and lowest sway measurements of both genders. Although

tested in the same conditions, the same spread was not observed within the male group. Of note, the female population of this sample was slightly larger than the male (19 females to 15 males) creating a possible bias. These findings are speculative and unable to be confirmed from this study alone. An opportunity lies for future research to expand upon the relationship of gender to postural stability.

Other characteristics noted in this study such as height, shoe size and BMI did not influence postural stability as represented by *Length of COP path* consistent with findings of Regind et al. (2003). Future research using a larger and more diverse sample population is necessary in order to establish more conclusive findings of these observations.

## 5. CONCLUSION

This study revealed that the designed protocol and the Medicauteurs *S-Plate* and software and the protocol are a sufficient method to obtain very good intra- and inter-session reliability of *Average Speed (M/L & A/P)* and *Length of COP path* in the presence and absence of visual information. *Area of COP path* and *RMSa* failed to prove reliable in this study with poor consistency both within and between sessions. Overall visual input did not make a significant difference to the intra-session reliability of measuring postural sway within this population however inter-session reliability was consistently greater in visually deprived conditions than in the presence of visual input supportive of previous reports.

The effect of subjective pain intensity, age, height, body mass index and shoe size did not appear to conclusively influence postural stability. As mentioned earlier, this population was largely a group of young healthy osteopathic students possibly limiting the influence of these variables. Within this sample population, females may have slightly poorer postural stability than males. This finding must be followed up using a more targeted study before such conclusions can be determined.

Recent research investigating the relationship of chronic pain to postural sway highlights the importance of future studies in this area particularly for those interested in manual therapeutic intervention for chronic pain. Researchers interested in the efficacy of manual therapy intervention could easily measure the effects of these interventions on postural sway. Before this can be done, the establishment of a standardised and reliable protocol is essential in order to truly compare studies that investigate correlations between chronic pain or other dysfunction with postural instability and the effects of therapeutic intervention.

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## **SECTION THREE**

### *Appendices*

## APPENDIX A



### **Information Sheet for Participants** **Intra-session and inter-session reliability of centre-of-pressure based sway measurements within a normal population.**

#### **Introduction**

I am a Masters of Osteopathy student, who is currently undertaking research as part of my course requirements. We are interested in establishing how reliable it is to measure postural sway over time in different individuals. This will be achieved by individuals standing on a force plate in a standardised position. Each participant will be required to complete 6 trials of 75 second duration with a 60 second rest between each trial. This procedure will be repeated once a week for the 2 following weeks.

#### **What is being asked of you?**

Prior to this study, we ask all participants to not deviate significantly from your day-to-day habits. This study requires you to stand barefoot on a force plate (a flat square device) with eyes open and later with eyes closed. Each session consists of 6 trials, which will take 30 minutes at the most. This procedure will be repeated 2 more times in the following 2 weeks. Sway measurements are recorded by the force plate software and will be analysed following the experiment. You will be supervised during each trial by the researcher. We will ask you complete a short questionnaire about any discomfort or pain you may or may not be experiencing in your everyday life. Additional information regarding your age, height, weight, shoe size (US), caffeine & nicotine intake will be recorded before beginning the study.

#### **What does this mean for you as a participant?**

- ★ You must be able to stand unassisted for 2 minutes
- ★ You must have no history of:
  - cerebellar, serious visual or audible dysfunction
  - dizziness or vertigo
  - recurrent faints, fits or blackouts
  - osteoporosis
  - central nervous system dysfunction (e.g. Parkinson's Disease, Alzheimer's or Stroke)
- ★ You are not and/or have not experienced any of the following:
  - difficulty walking,
  - recent violent trauma (motor vehicle accident, fall from height),
  - pain that wakes you during the night,
  - changes in bladder or bowel habits since pain began,
  - saddle anaesthesia (numbness around anus, perineum or genitals),
  - constant, progressive pain,
  - unexplained weight loss
  - previous history of cancer
- ★ Data gained doesn't require you to supply any personal information that could lead to your identification, so your confidentiality is preserved.
- ★ You are free to contact the researcher regarding any concerns or queries.
- ★ Data gained from this research will be used for submission of a Masters of Osteopathy thesis and may be used within a published journal article following the completion of the Masters degree.
- ★ **Participation is your choice, and you have the option to withdraw from the study up to two weeks post data collection, with no consequences.**

#### **Location:**

All data collection will take place at UNITEC New Zealand in building 115.

**Confidentiality**

The researcher aims to ensure that the information you have given is kept confidential. Data retrieved from the trial will be numbered, keeping the results confidential and will be entered within a computer programme that only the researcher and her supervisors can access. Raw copies of the data will be stored for five years following the study and will then be destroyed.

**Consent**

This information will be repeated to you before the commencement of the study with an opportunity for you to clear any doubts or concerns. Both verbal and written consent will be gained from you and it is taken as an indication that you consent to participate in this study.

**Thank you very much for your participation. If you have any questions at any time during the course of the study or following the completion of the study, please don't hesitate to contact me Sarah Fisher or my supervisor Dr Craig Hilton via email at [umaga\\_no13@hotmail.com](mailto:umaga_no13@hotmail.com) or [chilton@unitec.ac.nz](mailto:chilton@unitec.ac.nz)**

This study has been approved by the Unitec Research Ethics Committee from March 2009 to March 2010, UREC number is 2009.939. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretariat (Ph: 09 815-4321 ext 6162). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome



**Consent Form for Participants**  
**Intra-session and inter-session reliability of centre-of-pressure based sway measurements within a normal population.**

Participating in this study requires you to stand barefoot on a force plate (a flat square device) with eyes open and later with eyes closed. Each session consists of 6 trials, which will take 30 minutes at the most. This procedure will be repeated 2 more times in the following 2 weeks. Sway measurements are recorded by the force plate software and will be analysed following the experiment. You will be supervised during each trial by the researcher. We will ask you complete a short questionnaire about any discomfort or pain you may or may not experiencing in your everyday current life. Additional information regarding your age, height, weight, shoe size (US), caffeine & nicotine intake will be recorded before beginning the study.

This research is being conducted by Sarah Fisher from the Masters of Osteopathy at Unitec Institute of Technology, and will be supervised by Dr Craig Hilton. Findings from this research will be used to complete the Master of Osteopathy degree and may be used within a published journal article.

**Name of Participant:**.....

I have seen the Information Sheet for participants taking part in the above Masters study. I have had the opportunity to read the contents of the information sheet and to discuss the study with the researching team and I am satisfied with the explanations I have been given. I understand that taking part in this study is voluntary; that I can withdraw from the study up to two weeks post data collection, and that no data gained from the study can lead to my identification so that my anonymity is preserved.

**I understand that I can withdraw from the trial without any consequence if, for any reason, I want to.**

I understand that my participation in this study is confidential and that no data or information gained could breach this confidentiality.

I have read and understood the health-screening questionnaire and details given are accurate to my knowledge.

I have no history of:

- cerebellar, serious visual or audible dysfunction
- dizziness or vertigo
- insomnia
- recurrent faints, fits or blackouts
- osteoporosis
- cancer
- central nervous system dysfunction (e.g. Parkinson's Disease, Alzheimer's or Stroke)
- taking psychoactive medication (benzodiazepines or diazepam)

I am not and have not experienced any of the following:

- difficulty walking
- recent violent trauma (motor vehicle accident, fall from height)
- pain that wakes you during the night
- changes in bladder or bowel habits since pain began
- saddle anaesthesia (numbness around anus, perineum or genitals)
- constant, progressive pain
- unexplained weight loss

I am able to stand unassisted for 2 minutes.

I have had enough time to consider whether I want to take part.

I know whom to contact if I have any questions or concerns about the study.

The **principal researcher** for this study is Sarah Fisher, who is contactable via email at umaga\_no13@hotmail.com.

The **supervisor**, Dr Craig Hilton can be contacted via email at chilton@unitec.ac.nz.

Signature of Participant..... (date)

Study explained by.....

Signature of Researcher ..... (date)

*This study has been approved by the Unitec Research Ethics Committee from March 2009 to March 2010, UREC number 2009.939. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretariat (Ph: 09 815-4321 ext 6162). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.*

**APPENDIX B**

Number: \_\_\_\_\_

**Health Screening Questionnaire**

Age: \_\_\_\_\_

Gender: M F (please circle one)

Height: \_\_\_\_\_ (cm)

Weight: \_\_\_\_\_ (Kgs)

Shoe size: \_\_\_\_\_ (US)

BMI: \_\_\_\_\_

Daily caffeine intake (cups per day): \_\_\_\_\_

Cups of caffeinated drinks drunk this morning: \_\_\_\_\_

Do you smoke: YES NO (please circle one)

Number of cigarettes smoked this morning: \_\_\_\_\_

Average alcohol intake per week: \_\_\_\_\_

No. of alcoholic drinks consumed in the last 10 hrs: 0-2 3-5 6+ (please circle one)

Average number of hours slept per night: \_\_\_\_\_

Number of hours slept last night: \_\_\_\_\_

Are you currently on any medication? YES NO (please circle one)

If so, please name: \_\_\_\_\_

**VAS Scale:** No pain \_\_\_\_\_ worst possible pain

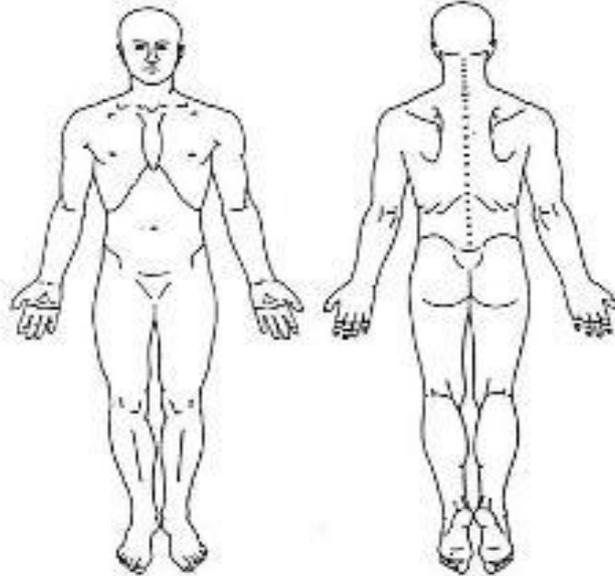
0 1 2 3 4 5 6 7 8 9 10

**Chronicity of pain:** 0-6 weeks 6-12 weeks 12+ weeks

- (please circle one)
- 1. Do you have trouble walking? YES NO
  - 2. Have you suffered any recent violent trauma?  
(e.g. motor vehicle accident, fall from height) YES NO
  - 3. Do you experience any night pain?  
(pain that wakes you during the night) YES NO
  - 4. Have you noticed any recent change in your bladder

- or bowel habits? YES NO
5. Do you suffer from sharp shooting pain down any limb? YES NO
6. Do you suffer from saddle anaesthesia  
(numbness around anus, perineum or genitals) YES NO
7. Is your pain constant and progressive? YES NO
8. Have you experienced any unexplained weight loss? YES NO
9. Do you have a previous history of cancer? YES NO

**Body Chart:** (please shade in any areas of pain you are currently experiencing)



**Troublesomeness Grid:** During the last month, how troublesome have each of the following areas been (please tick the appropriate box on each row for each area that you have pain)

	No pain	Not at all troublesome	Slightly troublesome	Moderately troublesome	Very troublesome	Extremely troublesome
Headache						
Neck Pain						
Shoulder Pain						
Elbow Pain						
Wrist/hand Pain						
Chest Pain						
Abdominal Pain						
Upper back pain						
Lower back pain						
Hip/thigh pain						
Knee pain						
Ankle/foot pain						
Other pains						

## APPENDIX C

*Journal: Gait & Posture*

### Author Notes

#### Guide for authors

Official Journal of: Gait and Clinical Movement Analysis Society (GCMAS), European Society of Movement Analysis in Adults and Children (ESMAC), Società Italiana di Analisi del Movimento in Clinica (SIAMOC), and the International Society for Posture and Gait Research (ISPGR).

**Authors should submit online:** <http://ees.elsevier.com/gaipos>. This is the Elsevier web-based submission and review system. You will find full instructions located on this site in the Tutorial for Authors. Please follow the guidelines to prepare and upload your article. Once the uploading is done, the system automatically creates an electronic pdf which is used for reviewing. All correspondence, including notification of the Editor's decision and requests for revisions, will be managed via this system.

A manuscript submitted to this journal can only be published if it (or a similar version) has not been published and will not be simultaneously submitted or published elsewhere. A violation of this condition is considered fraud, and will be addressed by appropriate sanctions. Two manuscripts are considered similar if they concern the same hypothesis, question or goal, using the same methods and/or essentially similar data.

#### Preparation of the Manuscript

1. Article types accepted are: Original Article (Full paper or Short Communication), Review Article, Technical Note, Book Review. Word limits including the abstract are as follows: Full paper 3,000 words plus no more than 5 figures/tables in total; Short Communication or Technical Note 1,200 words plus no more than 3 figures/tables in total. If the Editor feels that a paper submitted as a Full Paper would be more appropriate for the Short Communications section, then a shortened version will be requested. References should be limited to 30 for Full Papers, 15 for Short Papers and 10 for Technical Notes. An abstract not exceeding one paragraph of 250 words should appear at the beginning of each Article. The recommended word limit for Review Papers is 6,000 words. Authors must state the number of words when submitting.

2. All publications will be in English. Authors whose 'first' language is not English should arrange for their manuscripts to be written in idiomatic English before submission. A concise style avoiding jargon is preferred.

3. Authors should supply up to five keywords that may be modified by the Editors.

4. Acknowledgements should be included in the title page. Include external sources of support.

5. The text should be ready for setting in type and should be carefully checked for errors. Scripts should be typed double-spaced on one side of the paper only. Please do not underline anything, leave wide margins and number every sheet.

6. All illustrations should accompany the typescript, but not be inserted in the text. Refer to photographs, charts, and diagrams as 'figures' and number consecutively in order of appearance in the text. Substantive captions for each figure explaining the major point or points should be typed on a separate sheet.

7. Tables should be presented on separate sheets of paper and labeled consecutively but the captions should accompany the table.

8. Authors should also note that files containing text, figures, tables or multimedia data can be placed in a supplementary data file which will be accessible via ScienceDirect (see later section for further details).

9. When submitting your paper please ensure that you separate any identifying author or institution of origin names and details and place them in the title page (with authors and addresses). Submissions including identifying details in the manuscript text will be returned to the author.

#### *Summary of Overall Arrangement of Manuscripts*

You should arrange your contribution in the following order:

1. A cover page with complete details of the title, the source, and the authors full contact details. Acknowledgements should be placed on this page.
2. An abstract outlining the purpose, scope and conclusions of the paper.
3. The text suitably divided under headings. (frequently Introduction, Material or Patients, Methods, Results, Discussion will prove satisfactory)
4. References.
5. Tables with captions (each on a separate sheet).
6. Captions to illustrations (grouped on a separate sheet or sheets).
7. Illustrations, each on a separate sheet containing no text

#### **Illustrations**

Authors are required to provide electronic versions of their illustrations. Information relating to the preferred formats for artwork may be found at External link <http://www.elsevier.com/wps/find/authors.authors/authorartworkinstructions>.

#### **References**

Indicate references to the literature in the text by superior Arabic numerals that run consecutively through the paper in order of their appearance. Where you cite a reference more than once in the text, use the same number each time. References should take the following form:

1. Amis AA, Dawkins GPC. Functional anatomy of the anterior cruciate ligament. J Bone Joint Surg [Br] 1991; 73B: 260-267
2. Insall JN. Surgery of the Knee. New York: Churchill Livingstone; 1984
3. Shumway-Cook A, Woollacott M. Motor Control: Theory and Practical Applications. Baltimore: Williams and Wilkins; 1995.

Please ensure that references are complete, i.e. that they include, where relevant, author's name, article or book title, volume and issue number, publisher, year and page reference and comply with the reference style of Gait & Posture. Only salient and significant references should be included.

### **What information to include with the manuscript**

Having read the criteria for submissions, authors should specify in their letter of transmittal whether they are submitting their work as an Original Article (Full Paper or Short Communication), Review Article, Technical Note, or Book Review. Emphasis will be placed upon originality of concept and execution. Only papers not previously published will be accepted. Comments regarding articles published in the Journal are solicited and should be sent as "Letter to the Editor". Such Letters are subject to editorial review. They should be brief and succinct. When a published article is subjected to comment or criticism, the authors of that article will be invited to write a letter or reply.

A letter of transmittal must include the statement, "Each of the authors has read and concurs with the content in the final manuscript. The material within has not been and will not be submitted for publication elsewhere except as an abstract." The letter of transmittal must be from all co-authors. All authors should have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

All contributors who do not meet the criteria for authorship as defined above should be listed in an acknowledgements section. Examples of those who might be acknowledged include a person who provided purely technical help, writing assistance, or a department chair who provided only general support. Authors should disclose whether they had any writing assistance and identify the entity that paid for this assistance.

Work on human beings that is submitted to Gait & Posture should comply with the principles laid down in the Declaration of Helsinki; Recommendations guiding physicians in biomedical research involving human subjects. Adopted by the 18th World Medical Assembly, Helsinki, Finland, June 1964, amended by the 29th World Medical Assembly, Tokyo, Japan, October 1975, the 35th World Medical Assembly, Venice, Italy, October 1983, and the 41st World Medical Assembly, Hong Kong, September 1989. The manuscript should contain a statement that the work has been approved by the appropriate ethical committees related to the institution(s) in which it was performed and that subjects gave informed consent to the work. Studies involving experiments with animals must state that their care was in accordance with institution guidelines. Patients' and volunteers' names, initials, and hospital numbers should not be used.

At the end of the text, under a subheading "Conflict of interest statement" all authors must disclose any financial and personal relationships with other people or organisations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding.

All sources of funding should be declared as an acknowledgement. Authors should declare the role of study sponsors, if any, in the study design, in the collection, analysis and interpretation of data; in the writing of the manuscript; and in the

decision to submit the manuscript for publication. If the study sponsors had no such involvement, the authors should so state.

Authors are encouraged to suggest referees although the choice is left to the Editors. If you do, please supply their postal address and email address, if known to you.

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### **Randomised controlled trials**

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