THE UNIVERSITY OF HULL

Effects of cervical muscle fatigue protocol on balance and field-dependency

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by

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Summary

Cervical functional capacity outcome measures that are simple and reliable are urgently needed in order permit accurate assessment/reassessment during treatments and rehabilitation. Induced neck muscle fatigue has been shown to alter functional capacities such as balance and kinaesthetic sense in the standing posture.

A series of experiments were carried out in order to improve our general knowledge of neck functional capacities with the view to ultimately developing neck injuries management outcomes measures. In particular, the following questions were addressed 1) which optimal type of foam pads used during static computerised posturography are the most effective to enhance postural disturbances according each participant's weight and 2) what are the effects of various neck muscle groups fatigue on balance and on the perception of the subjective visual vertical and horizontal?

The results suggest that the foam pads selected for posturography should 1) possess a sufficiently high modulus of elasticity and 2) result in minimal deflection under the participant's load. Additionally, this thesis highlights the role of different muscle groups on functional capacities. Firstly, neck flexor and extensor muscle groups do not appear to play as much a significant role in our space awareness abilities as initially thought. Secondly, extensors and lateral flexor muscle groups appear to be major contributing factors to cervical functional capacities.

The novel approach used in this project provides results that challenge existing concepts on the role of different muscle groups on function. The new knowledge presented should help researchers in their development of more accurate and practical functional capacity testing protocol.

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Abbreviations

2D	2 dimensional
ANOVA	Analysis of variance
b1	Nuclear bag fibres 1
b2	Nuclear bag fibres 2
BCI	Brain-computer interfaces
cm	centimetre
CNS	Central nervous system
COG	Centre of gravity
COP	Centre of pressure
C-RFT^{dot}	Computerised Dot and Frame Test
CMRR	Common mode rejection ration
CV	Coefficient of variation
dB	Decibel
EEG	Electroencephalography
EMG	Electromyography
FD	Field dependent
FI	Field independent
FFT	Fast Fourier Transform
Hz	Hertz
IFD	Indentation force deflection
IVC	Isometric voluntary contraction
kg	Kilogram
kHz	Kilohertz
m	Metre
m^3	Cubic meter
MD	Median frequency
MIRGL	Modified Indentation Residual Gage Length Test

MVIC	Maximum voluntary isometric contraction
PS	Postural sway
RFT	Rod and frame test
RPE	Rating of Perceived Exertion
SD	Standard deviation
SE	Standard error
sEMG	Surface electromyography
SP	Static posturography
SVH	Subjective visual horizontal
SVV	Subjective visual vertical
V	Volt

Chapter 1 - Introduction

1.1 Background

Traumatic neck pain may result in long-term disability with up to 6% of patients not returning to work after one year (Cote et al., 2008, Fernandez-de-las-Penas et al., 2011). The pain felt by the patient may gradually subside, but there is a growing body of evidence indicating that some parameters of cervical function, such as balance and cervical proprioception, may not return to the pre-injury state (Roijezon et al., 2010, Yu et al., 2011, Treleaven, 2008). One of the major problems for the clinician in this situation is the inability to easily and accurately assess the neck's functional capacity (Humphreys, 2008).

Individuals who have experienced a cervical stress appear to experience cervical musculature fatigue more quickly, which in turn affects cervical proprioception and balance (Edmondston et al., 2011, Armijo-Olivo et al., 2010, Gosselin et al., 2004, Gosselin and Blouin, 2000, Gosselin and Almog, 2001). This cervical muscle fatigue can be measured by the use of surface electromyography (EMG). Of the EMG signals, the median frequency (MF) appears to be the most useful and objective measure for evaluating muscle function and fatigue (Arabadzhiev et al., 2010, Kallenberg and Hermens, 2008). During sustained muscle contraction, the power density spectrum of the EMG signal compresses toward lower frequencies, and this modification of the EMG signal correlates with fatigue (Oddsson et al., 1997). Even though the relationship between neck injury, neck pain and muscle fatigue is known, methods of assessment for disability in injuries to the cervical spine, especially those targeted at activities of daily living which are most affected by neck pain, are few in number (MacDermid et al., 2009). On the other hand, unsteadiness has long been recognised as a common symptom of whiplash-associated disorder and it is generally attributed to injury involving peripheral and/ or central components of the cervical somatosensory and vestibular system (Chester, 1991, Loudon et al., 1997, Rubin et al., 1995). The rather subjective perception of unsteadiness is likely to manifest as a measurable increased postural sway during quiet stance, which becomes a more objective and quantifiable measure of balance (Mancini and Horak, 2010, Gosselin and Schenk, 2002). However this simple inference is complicated by the abundance of controversy and uncertainty surrounding the functional importance of the neck proprioceptive systems for the control of quiet stance. Examination of postural sway by inducing altered cervical proprioception via muscle fatigue may thus provide the basis for a reliable means to assess the severity of neck pain and whiplash disorders (Gosselin et al., 2004, Edmondston et al., 2011, Almog and Gosselin, 2001).

Another type of cervical function assessment is the perception of the Subjective Visual Vertical (SVV) and Subjective Visual Horizontal (SVH), known as the "Rod and Frame test". These tests have been used for more than 50 years as an established way of investigating spatial orientation (Witkin, 1954). SVV/SVH have traditionally been measured by rotating manually a mechanical rod either with or without a frame present which introduces many errors in the measurement and interpretation of the results. However, a new computerised system is now available which improve the sensitivity and reliability of the test (Bagust, 2005). Recently, researchers have used the Rod-and-Frame test as a simple non-invasive method of assessing neck function (Grod and Diakow, 2002, Bagust et al., 2005, Humphreys, 2008).

To our knowledge, research into the effects of muscle fatigue has focussed predominantly on the extensors with work on neck flexor muscles only being reported recently. Four muscle groups contributing to eight different movements were investigated in this project. (Neck flexors, extensors and both lateral flexors).

1.1.1 Short description of key muscles

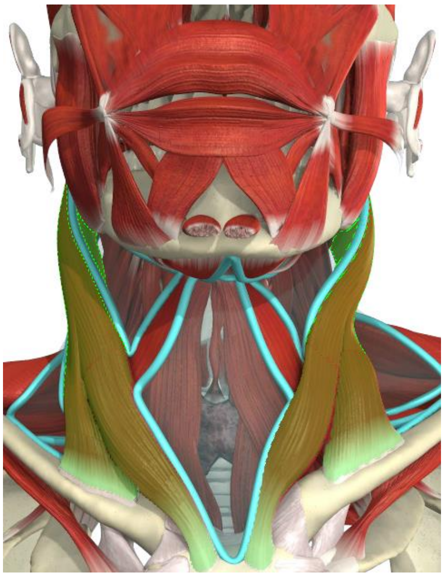


Figure 1 Sternocleidomastoid muscles (Adapted from Primal Pictures Ltd, 2011)

The sternocleidomastoid muscle lies on the side of the neck (Figure 1). The investing layer of deep cervical fascia, which splits to pass round it, encloses it. The muscle is an important landmark in the neck because many of the structures seen in both superficial and deep dissections can be directly related to it. The sternocleidomastoid muscle arises by two heads. The sternal head is tendinous and attached to the anterior surface of the manubrium sterni. The clavicular head is a wide muscular head arising from the upper surface of the medial third of the clavicle. The two heads merge and the muscle passes upwards, laterally and posteriorly to insert onto the lateral surface of the mastoid process of the temporal bone and the adjacent part of the superior nuchal line.

The SCM's actions vary according to whether one or both sternocleidomastoid muscles are activated. When one muscle acts, the head is tipped towards the shoulder on the same side and is rotated to direct the face towards the opposite side. When the muscles act together, the head is moved forwards.

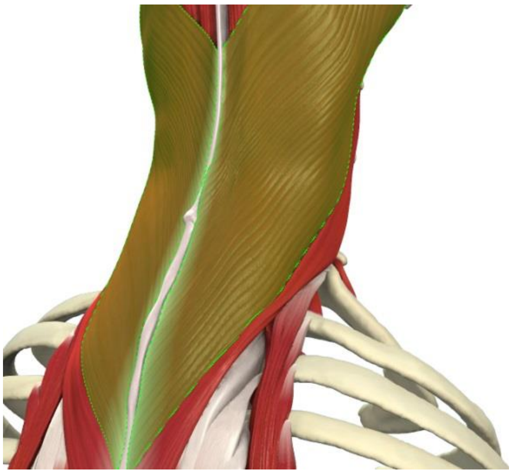


Figure 2 Splenius Capitis (Adapted from Primal Pictures Ltd, 2011)

Splenius capitis forms part of the floor of the posterior triangle of the neck, above and behind levator scapulae; it is deep to the rhomboid and trapezius (Figure 2). It is attached proximally to the lower half of the nuchal ligament, spinous processes of C7 to T4 and intervening supraspinous ligaments. Working individually the Splenius Capitis extends the head and neck, accompanied by lateral flexion of the neck and rotation of the face to the same side. Pure extension is achieved when both muscles act together.

Therefore, this project will investigate specifically areas concerning the effects of a neck muscle fatigue protocol in four different directions on functional capacities that hopefully will eventually lead to a greater understanding of the possible consequences of neck trauma or neck pain. Only then will it be possible to develop assessment measures for neck associated disorders.

1.2 Aims, objectives and null hypotheses

1.2.1 Aim

The aim of this project is to contribute to the general knowledge of neck functional capacities with the view of ultimately developing neck injuries management outcomes measures.

1.2.2 Objectives

- To measure the effects of various types of foam pads used during posturography on balance.
- To measure the effects of various neck muscle groups fatigue on balance.
- To measure the effects of various neck muscle groups fatigue on the perception of the SVV and SVH.
- To measure how subjects perceive their postural stability and exertion after neck muscle fatigue.

1.2.3 Research Hypotheses

Null hypotheses (H_0)

1. Four types of foam pads of different material properties used in static posturography do not increase the participant's sway velocity and centre of pressure displacement.
2. Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not change the muscles' myoelectric activity.
3. Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect balance.
4. Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect the subjective perception of vertical.
5. Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect the subjective perception of horizontal.

6. Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect the subjective perception of fatigue.
7. Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect the subjective perception of balance.

1.3 Overview of the thesis

The following describes briefly the contents of the remaining chapters of the thesis and will describe an overview of the approach taken as well as results obtained.

Firstly, a Literature Review describing in detail the scientific background of the project is presented in Chapter 2. Critical points of current knowledge including substantive findings, as well as theoretical and methodological contributions to the present topics are considered. The main goal of the review is to provide a more detailed analysis of existing literature and show deficiencies that motivated the present research. Posturography, postural control, muscle fatigue and electromyography are discussed extensively. Furthermore, the presentation of field-dependency as a tool for neck functional assessment is also reviewed. Finally, the subjective self-assessment of balance and fatigue are discussed in the context of assessments.

Chapter 3 describes the equipment used in the research and demonstrates its reliability and validity. A key element of the present project is the use of foam pads during static computerised posturography. Their material properties are therefore measured according to the American Society for Testing and Materials protocol (D-3574-11, 2012). This chapter also presents the neck fatigue apparatus built for this project and adapted from Schieppati, et al., (2003).

The first experiment using participants is presented in Chapter 4. It investigates how different foam pad surfaces affects balance. The effects of these different surfaces was measured using the portable force platform with velocity of postural sway (during quiet stance with eyes closed) being the posturographic parameter analysed.

If outcome measures can eventually be developed on the basis of this thesis it is important to investigate how functional parameters such as balance is affected by muscle fatigue protocols along with subjective components exhibited during testing. This is considered in Chapter 5, which presents measurement of the effect of sustained isometric cervical muscle contraction in eight different directions on balance and perceived stability in addition to the measurement of subjects' perception of fatigue and subjects' perception of change in balance. The muscle fatigue protocol involved the use of an adjustable mass held in a static position by the neck muscles over a certain period of time

The Computerised Dot and Frame (C-RFT^{dot}) Test has shown promise as a method of assessing the effects of cervical spine injury, but it has traditionally been performed in the sitting position. For the purpose of this research, the participants were required to take the test in a standing position in order to measure balance simultaneously. Chapter 6 describes the validation of the C-RFT^{dot} test in the standing posture and confirms the agreement between the sitting and the standing results, and measures the effects of cervical muscle fatigue on field-dependency as measured by the C-RFT^{dot} test.

Chapter 7 discusses the implications of the findings and relates the research to the current literature. It will also critically examine the findings in the light of the previous state of the subject as outlined in the background, and make judgments as to what has been learnt in the work.

Finally, Chapter 8 presents the conclusion and suggestions for further work.

Also included in the thesis are three appendices which present (A) the participant information sheets and consent forms for each experiment involving participants, (B) The Standard Test Methods for Flexible Cellular

Materials-slab, Bonded, and Molded Urethane Foams, Designation: D3674-11, (C) Publications from the present thesis, and (D) description of statistical tests used in this thesis.

Chapter 2 - Literature Review

2.1 Introduction

This following reviews our current understanding of the regulatory mechanisms involved in the control of quiet stance and the effects that neck pain/injury might have on these mechanisms. It also considers how cervical muscle fatigue can alter the posturographic profile of healthy individuals. Finally, the recent use of the perception of subjective visual vertical (SVV) and horizontal (SVH) in subjects suffering from neck pain and whiplash is reviewed in the context of developing objective and accurate outcome measures.

2.2 Postural control

2.2.1 Quiet stance

Quiet stance represents a state of dynamic equilibrium, where small excursions of the body's centre of mass are counteracted by internally generated active and passive forces (Gage et al., 2004). Sensory information from at least three sources is thought to contribute to the control of quiet standing: (1) the somatosensory system, (2) the vestibular system, and (3) vision. Yet, dependence on information from any one of these sources appears unnecessary, since many patients with loss of somatosensory, vestibular or visual function are capable of independent stance (Horak et al., 1990).

The apparent notion of sensory redundancy within the control of stance therefore necessitates a certain degree of central sensory convergence and integration. In line with encephalic morphologic and physiologic characteristics, this convergence and integration is thought to occur principally in the vestibular nuclei, as well as in the cerebellum, the cerebral cortex, brain stem, thalamus and basal nuclei (Horak and Hlavacka, 2001, Redfern et al., 2001, Rubin et al., 1995).

Corrective movements are needed to keep the centre of gravity within the base of support, which must be achieved through co-ordination of the sensory, skeletal muscle and central nervous systems. The parts of the postural control system are presented in Table 1 and in Figure 3.

Table 1 Postural control systems.

Sensory system	**Skeletal muscle system**	**CNS**
Vestibular system located in the inner ear (semicircular canals, otholiths, maculaes)	Muscles of the upper and lower extremities	Stretch reflex
Vision (retina)	Trunk muscles	Long-loop reflexes
Proprioceptive system (muscle spindle-type I and II, Golgi tendon organ, joint receptors)	Neck muscles	Preprogrammed reactions (Learned skills)
Cutaneous receptors		Synergistic action

Adapted from Kejonen (2002)

2.2.2 The somatosensory system in quiet stance

In the control of normal quiet standing on hard support surfaces a dominant role is assigned to the somatosensory system (Day et al., 2002, Fitzpatrick et al., 1994, Horak and Hlavacka, 2001). The somatosensory system consists of enteroceptive receptors, which include the muscle spindles, Golgi tendon organs and joint capsule receptors, all of which are proprioceptive, and exteroceptive receptors, such as mechanoreceptors in subcutaneous tissue. There is much debate regarding the importance of these different receptors and their anatomical location for the control of quiet stance.

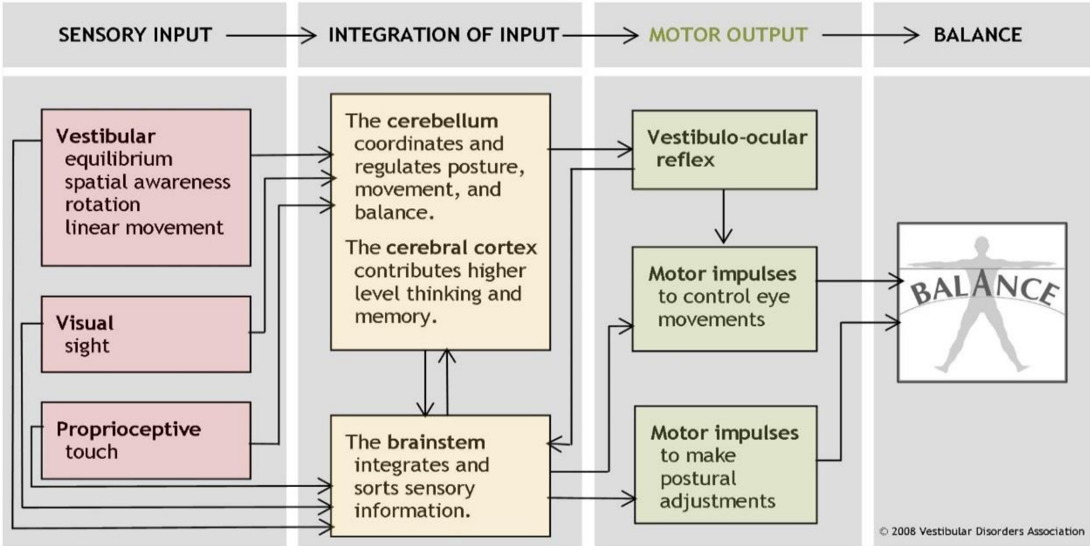


Figure 3 Example of the complex set of sensorimotor control systems necessary to achieve and maintain balance (Adapted from Black & Watson, 2008)

Traditionally lower leg somatosensation has been considered a crucial source for the regulation of quiet stance, especially in the light of numerous studies in which lower leg somatosensory input was reduced by ischaemia. Application of bilateral ischaemia above the knee joints, designed to disrupt proprioceptive input from the ankle joint muscles as well as somatosensory input from the feet, significantly increased postural sway, both with eyes open and with eyes closed. For example, Mauritz et al. (1980) and Diener et al. (1984) found that excluding afferent information from pressure and or joint receptors of the foot by placing pressure cuffs around the ankles of normal subjects affected postural stabilisation in the low frequency domain, with support surface translations of 0.3 Hz, but only when vision was excluded. They concluded that proprioceptive information from muscle spindles and Golgi tendon organs originating from above the level of the ankle is sufficient to stabilise higher frequency postural sway, whereas optimal control of low frequency sway require input from foot somatoreceptors (Mauritz et al., 1980, Diener et al., 1984).

In accordance with this, low frequency vibratory stimulation of the forefoot produced greater postural effects than ankle muscle vibration, the reverse being true for high frequency stimulation (Kavounoudias et al., 2001). Conversely, in another study, loss of somatosensory information from the feet by ischaemic hypoxia did not significantly affect postural sway under any of the visual and support surface conditions (Horak et al., 1990). A further study found that anaesthesia of the feet and ankles produced only small increases in body sway, which were not consistent between subjects and did not reach statistical significance (Fitzpatrick et al., 1994). Recently, Piedrahita cooled the lower limbs of subjects and measured the affected muscle function as well as the capability to maintain balance (Piedrahita et al., 2009). In this study the balance was affected by the intervention. However, the use of small numbers of subjects ($n < 10$) in each of the previous studies, limits the overall interpretation we can make.

The contradictory results communicated by these studies might be accounted for by the different methods of stimulation employed. Contrarieties might also have resulted from the fact that sway was measured as centre of foot pressure on a force platform in the studies by Diener et al. (1984), Kavounoudias et al. (2001) and Piedrahita (2009), whereas Horak et al. (1990) and Fitzpatrick et al. (1994) measured sway using a potentiometer attached to the hips or a spring attached to the tibial tuberosity, respectively. Arguably, centre of foot pressure is a more sensitive measure of low frequency, low amplitude postural sway and, based on the early hypothesis that foot somatoreceptors serve an important role in conferring postural stability at low frequency postural sway, measuring centre of foot pressure would be a more suitable means of determining differences when foot somatosensation is disrupted. Also, considering that most physiological systems operate via negative feedback mechanisms, it is conceivable that foot receptors, which respond to mechanical pressure changes, trigger a response that counteracts their stimulus. Disruption of somatosensory information from the feet may therefore lead primarily to decreased control over the centre of foot pressure, which is best measured directly using a force platform. Further, the attachment of the measuring device to the leg, which occurred in those studies where loss of foot somatosensation had little effect on postural sway, produces light tactile stimulation, which is known to stabilise sway (Rogers et al., 2001).

Apart from lower leg somatosensation, the role of trunk and especially neck proprioception for maintaining balance is gaining increased interest within the literature. Numerous studies have demonstrated poorer postural performance in patients suffering from chronic neck pain and following whiplash injury (Yu et al., 2011, Treleaven, 2008, Armstrong et al., 2008). The effect of such conditions on postural performance has generally been attributed to altered local proprioception.

With regard to chronic neck pain, poor posturographic performance has been ascribed to suboccipital muscle atrophy and fatty degeneration with consequent decreased activity of suboccipital muscle spindles (McPartland et al., 1997). Alternatively, chronic pain, if associated with increased muscular tension rather than atrophy and degeneration, may facilitate the accumulation of contraction metabolites. Contraction metabolites, including potassium ions, lactic acid and arachidonic acid, stimulate group III and IV afferents, which have the potential to initiate a positive feedback loop of increased muscle spindle sensitivity and thus activity via the gamma motor system (Figure 4) (Knutson, 2000).

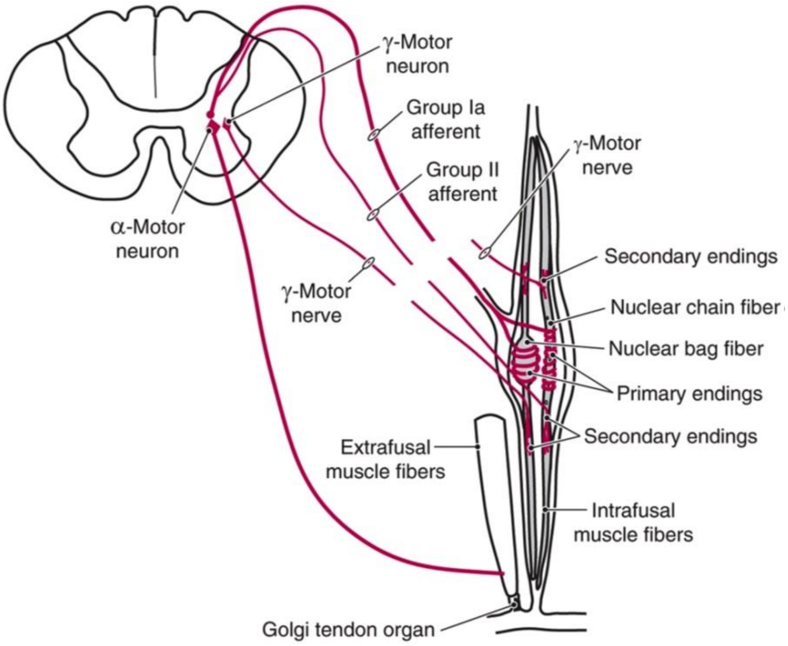


Figure 4 y-motor positive feedback loops (Knutson, 2000)

Chemonociceptors synapse on gamma cells, leading to stimulation of muscle spindles. Spindle stimulation causes Ia and II discharge. Group Ia neurons synapse mono-synaptically with alpha cells; group II synapse with alpha interneurons and gamma cells. The Ia and II excitation of the alpha cell leads to further muscle contraction, which causes increased group III and IV afferentation and completes a positive feedback loop. A second loop involves spindle group II excitation of gamma cells, which stimulate the muscle spindle and cause further group II discharge.

Further, since muscular tension and, hence, the concentration of metabolites is likely to be unequally distributed within the affected muscles, the muscle spindles may become unequally sensitised (Karlberg et al., 2002). The resultant increased, but erroneous proprioception is postulated to be associated with disturbed postural control (Knutson, 2000).

The effect of whiplash injury on cervical proprioception may be similar to the mechanism described previously, with gamma induced spindle hypersensitivity and aberrant activity leading to unsteadiness as well as other frequently voiced complaints, such as cervical vertigo. On the other hand, acute whiplash injury often induces an inflammatory response (Loudon et al., 1997). In contrast to contraction metabolites, inflammatory substances, such as bradykinin and prostaglandins, have been shown to decrease spindle output (Treleaven, 2008).

Patients suffering from chronic pain or whiplash injury may thus have impaired postural control attributable to either decreased or increased, but erroneous proprioception. Impaired postural control has also been observed in normal subjects following muscular fatigue. Vuillerme (2001) demonstrated that fatigue of the calf muscles increases postural sway in quiet stance (Vuillerme et al., 2001). Dorsal neck muscle fatigue induced by prolonged isometric contraction of the neck extensors also resulted in increased postural sway during quiet stance (Figure 5) (Gosselin et al., 2004, Schieppati et al., 2003, Stapley et al., 2006).

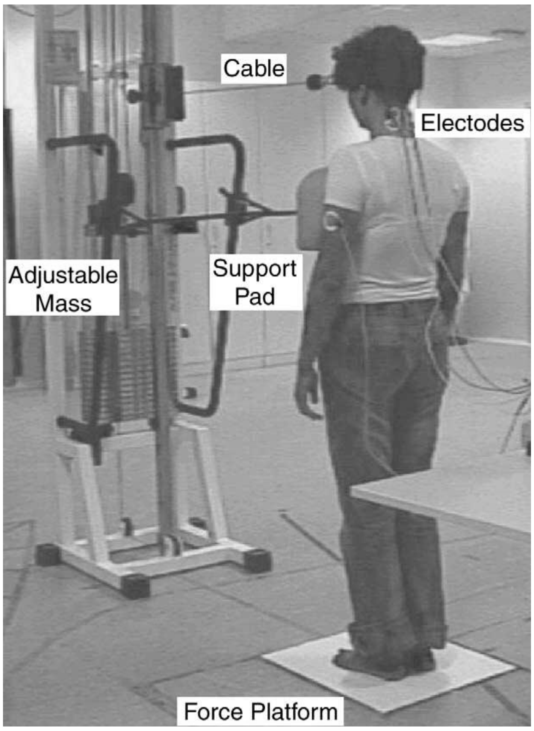


Figure 5 Experimental setup used by Schieppati et al. (2003) and by Stapley et al. (2006) to measure the effects of neck extensor muscle fatigue on balance (Adapted from Schieppati, 2003).

Other studies, which examined the effect of dorsal cervical and lumbar muscular fatigue on kinaesthetic sensibility, found muscular fatigue to be correlated with decreased kinaesthetic sensibility (Taimela et al., 1999, Pinsault and Vuillerme, 2010), thus implying a reduction in 'meaningful' conscious proprioception.

2.2.3 Muscular fatigue and balance

Muscular fatigue can be described as an exercise-induced reduction in the ability of muscle to produce force or power, whether or not the task can be sustained (Meeusen et al., 2006, Nybo and Secher, 2004). Importantly, it is recognised that the reduction begins soon after the onset of sustained physical activity (Bigland-Ritchie et al., 1986). What makes muscles fatigue? One or several of the physiological processes that enable the contractile proteins to generate a force become impaired. Therefore more important than muscle fibre types involved in the contraction, is the recognition that the site of impairment depends on the task being performed. This effect is known as the task dependency of muscle fatigue and is one of the principles to have emerged in this field over the last 100 years (Enoka and Duchateau, 2008).

As briefly mentioned in the previous section, muscular fatigue can be either caused by processes in the muscles or in those parts of the nervous system that activate the involved muscles. Investigators have thus been attempting to distinguish between an impairment of contractile protein function and a decrease in the magnitude of the activation signal (Noakes et al., 2001, Noakes, 2000). Noakes proposed a model in which a central, neural governor constrains the cardiac output by regulating the mass of skeletal muscle that can be activated during maximal exercise in both acute and chronic hypoxia. Specifically, they stated that a specific brain centre provides a feed-forward regulation of the intensity of vigorous effort in order to conserve homeostasis, protecting vital organs such as the brain, heart and skeletal muscle against damage from hyperthermia, ischemia and other manifestations of catastrophic failure.

Recently others have come to dispute the existence of a 'Central Governor', (Shephard, 2009, Brink-Elfegoun et al., 2007, Noakes, 2012). These authors state there is a lack of convincing experimental evidence to support the corollaries of the hypothesis; furthermore, some findings, such as the rather consistent demonstration of an oxygen consumption plateau in young adults, argue strongly against the limiting role of a 'Central Governor'. Therefore it is reasonable to assume that just as muscle fibres require energy, produce metabolites, generate heat, and need a neurotransmitter to enable activation, so too do the neurons in the cerebral cortex but unfortunately, the exact mechanism are still unknown.

In the cervical region, a disproportionally high density of muscle spindles can be found within the small intrinsic, deep dorsal and suboccipital musculature (Nitz and Peck, 1986, Peck et al., 1984, Treleaven, 2008). It is these muscle spindles rather than the various mechanoreceptors found within the cervical facet joint capsules that are likely to provide the main contribution to neck proprioception (Kogler et al., 2000, Palmgren et al., 2009, Rix and Bagust, 2001). Muscle spindles contain both larger nuclear bag fibres and smaller nuclear chain fibres. Nuclear bag fibres can be divided into bag $_1$ (b_1) and bag $_2$ (b_2), based on their actions relative to muscle motion. Bag $_1$ intrafusal fibres are innervated by dynamic gamma motor neurones, whereas bag $_2$ and chain fibres are innervated by tonic gamma motor neurones (Figure 6). An interesting property of the deep cervical muscle spindle complex is that about one third of Ia afferents originate in muscle spindles that lack b_1 fibres (Price and Dutia, 1989). It can thus be inferred that the deep cervical muscles are concerned more with background muscle tone than consciously controlled movement, and that tonic b_2c spindles may play an important postural role. If the latter is indeed true, then fatigue of the deep neck muscles has considerable potential for disrupting postural control, especially since it has been implied that metabolites of muscle contraction preferentially stimulate tonic gamma motor neurones (Djupsjobacka et al., 1995).

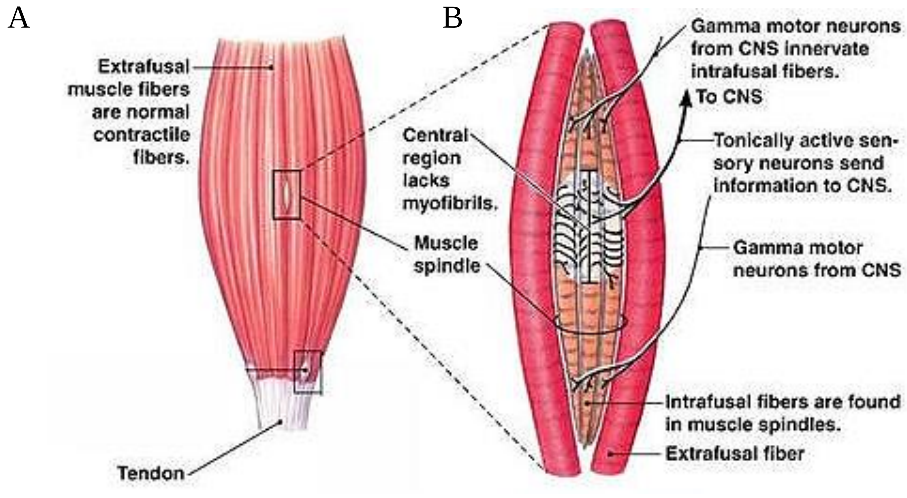


Figure 6 Muscle spindle (Adapted from www.studyblue.com)

A. Muscles spindles are buried among the extrafusal fibres of the muscle. B. Muscle spindle sends information about muscle stretch to the CNS. (StudyBlue Inc. http://www.studyblue.com/notes/note/n/movement-science-motor-control/deck/1421471)

If the concept that muscular fatigue produces erroneous or aberrant proprioceptive afferent input is valid, then the effect of muscular fatigue might be comparable with that of a low frequency vibratory stimulus applied to the respective muscles. Similar to the effect of a high concentration of muscle metabolites, vibration applied to relaxed muscles gives rise to tonic muscular contraction (Ledin et al., 2003). Vibration has been demonstrated to be one of the most effective modes of stimulation to activate muscle spindles with the effector site of the vibratory stimulus thought to be located principally in the secondary endings of the muscle spindle, which originate in the bag $_2$ and chain fibres and are considered to regulate posture (Eklund, 1973, Pyykko et al., 1991, Yagi et al., 2000).

Vibration applied to the dorsal neck muscles causes erroneous proprioceptive input, which consistently produces anterograde body sway. This is in contrast to calf muscle vibration, which produces retrograde body sway (Ledin et al., 2003, Lekhel et al., 1998). This contrariety is attributed to different frames of reference with which proprioceptive input from the calf and neck muscles is processed. Central processing of neck afferents is believed to occur in reference to the head, whereas calf proprioceptive input is thought to be processed with the support surface taken as a reference (Lekhel et al., 1998).

It has been observed that vibration-induced shifts in body posture build up gradually contrasting with the effects of fast stretch reflexes (Pyykko et al., 1989, Thompson et al., 2010). This suggests that a form of regulation other than reflex control prevails in the organisation of postural responses. Significant sway responses to vibration of the following muscles have been found (in order of maximum response): dorsal neck, triceps surae, gluteal, abdominal, hamstring, quadriceps, dorsal lumbar and tibialis anterior muscles (Pyykkö et al., 1989). It could be argued that the response obtained following vibration of the dorsal neck muscles holds little or no implications for the control of quiet stance, since muscle spindle activation of such magnitude with the head in the neutral position would, considering the neck's anatomical location, only occur during severe body tilt. However, as the maximum response obtained through vibration of the remaining muscles was not in order of their proximal to distal anatomical location, it is likely that the results were, at least to some extent, related to functional rather than anatomical properties.

Further evidence to support the functional importance of neck proprioception is available. For example, vibration applied to the cervical paraspinal muscles in forest workers suffering from tension neck induced significantly more postural sway compared with control subjects (Koskimies et al., 1997). Similarly, patients with chronic cervicobrachial pain syndrome exhibited increased sway compared with healthy individuals in response to neck muscle vibration (Gomez et al., 2009).

2.2.4 The vestibular system in quiet stance

Whereas somatoafferent input appears to contribute greatly to the control of quiet stance, the importance of vestibular input is questionable. A number of studies have shown bilateral peripheral vestibular deficits to have little effect on postural sway and thus balance during static posturography in the absence of conflicting sensory input when somatosensory with or without visual information was available (Horak et al., 1990, Fitzpatrick et al., 1994, Nashner et al., 1982). It is worth noting, however, that the patients who participated in these studies suffered chronic vestibular loss, which implies that some form of central compensation facilitated by neuronal plasticity may have occurred (Day et al., 2002). Few studies have examined the effect of acute bilateral vestibular loss on postural sway, but acute vestibular loss is widely recognised to be more deleterious than chronic vestibular loss (El-Kahky et al., 2000).

It has been argued that vestibular thresholds are too high for the perception of sway during quiet standing (Winter et al., 1998). However, this argument is based mainly on a study which investigated perception in the sense that subjects consciously detected an event and could reliably report on it (Fitzpatrick et al., 1994) but the fact that detection and processing may occur at a subconscious level with different, lower thresholds, was ignored.

Assuming that vestibular thresholds are low enough, the most likely vestibular receptors to be involved in the detection of sway at frequencies normally occurring during quiet stance (0.3-1 Hz) are the otolith organs rather than the semicircular canals (Demer et al., 1993). The otolith organs, i.e. the utricle and saccule, are two membranous sac-like structures located within the vestibular labyrinth of the inner ear at the junction of the three semicircular canals (Ohmi, 1996).

Even if vestibular thresholds are low enough to detect sway during quiet stance, it is unlikely that vestibular signals operate directly and independently of other sensory signals to control normal upright standing. It has been suggested that in the control of stance the vestibular system only comes into play when the support surface is perceived as moving (Maurer et al., 2000) or somatosensory information is inadequate (Horak and Hlavacka, 2001). If, for example, the support surface is tilted backwards, the signal arising from lower limb proprioceptors is similar to that arising when the support surface is translated backwards. In such a situation, patients with bilateral vestibular loss exhibit an anticompensatory postural response, which invariably results in a fall (Maurer et al., 2000). A major role of the vestibular system may thus be to solve problems of conflicting sensory information.

A significant contribution of vestibular input to the control of normal quiet stance has repeatedly been dismissed in the light of studies that have failed to show increased postural sway in patients with chronic bilateral vestibular loss, when somatosensory input was unperturbed (Horak and Hlavacka, 2001, Mancini and Horak, 2010). However, it needs to be considered that the compensatory plastic neuronal modulation thought to occur with chronic vestibular loss constitutes a major abnormality within the balance control system, which renders comparison to normal, healthy subjects problematic. Also, in addition to solving sensory conflicts, it is likely that the vestibular system serves to modulate the sensitivity of the somatosensory system. This is thought to occur principally through the gamma motor system, which has lower firing thresholds than the alpha motor system and would thus take effect before vestibulospinal reflexes were observable or measurable (Dutia, 2010). However, vestibulospinal connections appear to involve primarily the axial and proximal limb muscles, but not the distal lower limb muscles, especially not the triceps surae muscles, which are thought to provide a major part of the sensory input for the control of quiet standing (Allum and Honegger, 1998, Fitzpatrick et al., 1994). The vestibulospinal gamma pathway on its own could thus only contribute significantly to static postural control if trunk and especially neck proprioception played an important role in the control of quiet stance. It is known that disturbed trunk and neck proprioception have the potential to disrupt postural control (Bove et al., 2007, Bove et al., 2006, Pyykko et al., 1991, Treleaven et al., 2003), but it is not known whether axial proprioception actively contributes to the regulation of quiet stance.

2.2.5 Multisensory mechanisms of stance control

Apart from a possible vestibular-somatosensory interaction through the gamma system, the central convergence of somatosensory, vestibular and visual inputs, primarily in the vestibular nuclei, may facilitate the interaction of these three sensory channels at a pre-motor stage (Day et al., 2002). It has been proposed that information from each of the sensory channels is weighted dynamically in a competitive manner, such that each sensory channel has a modulating influence of varying potency on balance control (Day and Cole, 2002).

Therefore, it is unlikely that the vestibular system, or any of the other two sensory systems, should not contribute in one way or another to the control of quiet standing. By stating that the vestibular system has no influence when somatosensory information is available, the central modulation and vestibular-gamma hypotheses are effectively rejected, leaving only reflex or stiffness control of quiet stance.

Reflex control would involve predominantly somatosensory reflexes that are complemented or overridden by vestibular reflexes when somatosensory reflexes alone become inadequate or inappropriate. Reflex control of quiet standing is however unlikely, since the angular motion occurring at the ankle is less than necessary to elicit a stretch reflex in the foot or ankle muscles and, more importantly, because the EMG activity of the gastrocnemius muscle has been shown to anticipate anteroposterior motions of the centre of gravity and COP during quiet stance (Gatev et al., 1999). Stiffness control, as proposed by Winter et al. (1998), is by itself also unlikely, since there is evidence against continuous triceps surae activity during quiet stance, which questions the proposed mechanism for maintaining stiffness at the ankle joint (Gatev et al., 1999, Morasso and Schieppati, 1999, Qu et al., 2007) Also, it has been demonstrated that ankle stiffness was not altered when postural sway was reduced by allowing visual feedback or by the subject's intent to minimise postural sway (Sasagawa et al., 2009).

The evidence thus suggests a contribution of a central anticipatory feed-forward control of quiet stance, which may be supplemented by a form of stiffness control, where small, expected exploratory excursions in field of gravity are permitted, so that sensory input from the various receptors can be used to continuously update the internal representation of stance (Finley et al., 2009, Morasso and Sanguineti, 2002). Such feed-forward anticipatory control is compatible with both the central modulation and vestibular-gamma hypotheses.

2.2.6 Summary of postural control

In summary, there is little doubt that the somatosensory system in its entirety provides a considerable portion of the sensory input required for the control of quiet stance. However, the relative importance of individual receptors, pertaining especially to their functional properties and anatomical location, is poorly understood and warrants further study. The role of the vestibular system is equally enigmatic, but is most likely related to its interaction with and modulation of somatosensory information. The final sensory contribution to balance, which so far has only received a brief mention, is the visual system. The consensus with regard to visual information appears to be that it acts to stabilise quiet stance, especially when other sensory information is unavailable or unreliable, but is considered less critical than somatosensory information (Fitzpatrick et al., 1994, Horak and Hlavacka, 2001) Fitzpatrick et al., 1994; Horak and Hlavacka, 2001; Loram et al., 2000). On the other hand, vision is definitely an important contributor to maintain a steady stance in elderly adults (Aartolahti et al., 2013, Chen et al., 2012). A major point of interest concerning visual information is that, similar to the other sensory inputs, its removal is thought to trigger a central re-weighting process, which places more dependence on the still available inputs (Redfern et al., 2001; Vuillerme et al., 2001). Support for the existence of such central re-weighting mechanisms can be derived from studies, which investigated the effects of multiple sensory perturbation. With respect to standing balance it has repeatedly been found for quite some time that, when multiple sensory systems are impaired or eliminated together, the resulting increases in postural sway often show exponential tendencies, that is the increase in sway is greater than the additive effect of each system being affected singularly (Woolley et al., 1993, Polastri and Barela, 2013). The picture is thus one of an integrative central mechanism, which is likely to operate anticipatory feed-forward control, based on prior sensory information, rather than reflex-driven feedback control.

In order to gain further insight into the complexities of static balance control, it may be useful to examine the effect of sensory perturbations, designed to influence the postural control system in ways other than through spinal, vestibulospinal, or vestibulocollic alpha-mediated reflexes, which are unlikely to be involved in the control of quiet stance (Allum, et al, 1997).

2.3 Foam pads in posturography

The advent of computers has helped further our understanding of postural characteristics during quiet stance and during gait. Although static posturography (SP) is widely used to measure balance impairments, contrasting data have also been reported (Pinsault and Vuillerme, 2009, Ruhe et al., 2010). The main limiting factor of SP is due to its intrinsic inter-individual high variability (Di Berardino et al., 2009). Investigators have attempted to decrease what is considered unacceptable variation by introducing dynamic disturbances during quiet stance (Koozekanani et al., 1980, Cyr et al., 1988). Some methods create somatosensory and/or visual disturbances by altering the position of the force platform and visual screen. Although very versatile in the extent to which all systems contributing to balance can be evaluated, dynamic posturography remains prohibitively expensive and far too complex for mass utilisation.

One method used to introduce instability in the posture stance is the use of foam pads placed under the feet. The application of foam at the force platform/feet interface was first described in 1972 (Kapteyn, 1972), but only a few studies were reported over the next 30 years (Amblard and Cremieux, 1976, Brandt et al., 1981, Amblard et al., 1985, Kantner et al., 1991, Dujols, 1991, Saling et al., 1991, Norre, 1992, Norre, 1993, Norre, 1995, Nordahl et al., 2000, Grigorova et al., 2001, Rogers et al., 2001). Researchers started to use foam pads more regularly since 2002 in order to refine the static posturography procedures.

Standing on foam is believed to exaggerate balance deficits by decreasing the reliability of somatosensory information from cutaneous mechanoreceptors on the plantar soles and by altering the effectiveness of ankle torque (Di Berardino et al., 2009). Although this method is promising, its use is still not standardised. Three studies have looked at different foam thickness. In 1995, Woolley first carried out laboratory tests to define four different types of foam pads used in posturography and suggested the thickness might be important in order to avoid inaccurate diagnosis of a patient's reliance on a particular sensory input (S.M. et al., 1995). Their results showed that different types of foam pads give different results on clinical evaluation with the stabilometric platform, thus underlining the importance of knowing and specifying the characteristics of the foam pads used. This was confirmed more recently by measuring foam pads of different thicknesses and densities but optimal thickness was not recommended (Kong et al., 2007). Patel measured body movement with a Zebris ultra-sound movement detection system (Zebris Medical GmbH, Isny im Allgäu) while using foam pads of different properties (Patel et al., 2008). The pads firmness was described as "firm foam, medium foam, and soft foam but no details of stiffness or other material properties were reported. Their results showed that movement variance increased significantly when standing on all foam surfaces compared with a solid surface (no foam), including the firm foam (Patel et al., 2008). Nearly all recent published papers, with the exception of Vuillerme et al., (2005), who used 2cm foam pads, report the use of foam pads of 10cm thickness but no justification is given for the choice of this thickness. More recently, Ceria-Ulep (2010) integrated foam pads in a study using the National Health and Nutrition Examination Survey (NHANES), and although balance tests with eyes closed did indeed produce significant changes in measured parameters, the reliability correlation was only 0.26. Again no mechanical properties of the foam pads used were reported.

Thus it would appear that foam pads are routinely used in assessment protocols. In 2007, Treleaven reported the use of "dense" foam pads into her "clinical assessment of sensorimotor control disturbances in neck disorders" (Treleaven, 2008), but once again a 10cm form thickness is recommended without reference to any specific range of stiffness. Only three papers appear to provide details of the foam pads used. The first article investigated the kinematic analysis of the hip and trunk during bilateral stance on firm, foam and multiaxial support surfaces. In this instance the height of the foam was not mentioned but the density was reported as 54.53 kg/m^3 (Blackburn et al., 2003). The second study to report the foam property looked into trunk sway measurements during stance and gait tasks in Parkinson's disease (Adkin et al., 2005). The foam pads they used had a height of 10cm, and a density of 25 kg/m^3. Lastly, Di Bernardino (2009) evaluated the effects of standing on two different types of rubber foam pads: a "monolayer" with a thickness of 10 cm and a density of 25 kg/m^3 and a "bilayer" with a thickness of 8 cm and a density of 100 kg/m^3 (Figure 7).

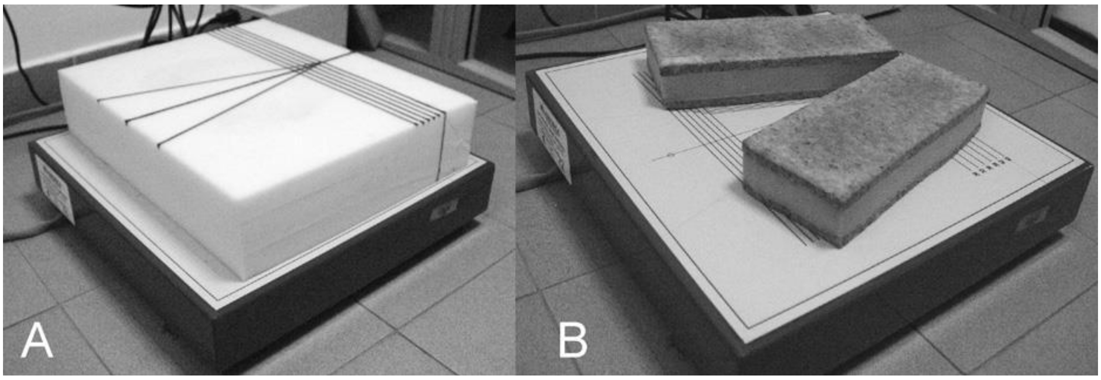


Figure 7 Monolayer (A) and bilayer (B) rubber foam pads (Adapted from Di Berardino et al., 2009).

Di Berardino's results showed that the variability of static posturography parameters was significantly reduced by the use of both foam pads. However, the comparison of the two types of foam pad was also statistically significant with the bilayer type with the lowest coefficient of variation CV at 10% compared with 14.4% with the monolayer. For static posturography to be used as a reliable clinical tool, it is necessary to use protocols that will achieve a CV lower than 15% (Shah et al., 1991, Di Berardino et al., 2009). Therefore, Di Berardino's study suggests that higher density foam pads are better for clinical use. Thus all three studies (Blackburn et al., Adkin et al., di Bevardino et al) reported a significant change in posturographic parameter but due to their different methodologies it is impossible to compare them reliably.

From the information presented above, it would appear that foam pads density by itself is not a sufficient characteristic in the selection of a useful pad for static posturograpy. The stiffness of a foam sample as expressed by the elastic modulus may represent a more pertinent characteristic.

2.3.1 Foam pad characteristics

Different methods are available to characterize the mechanical properties of foams. The system which appears to be most widely accepted is the one developed by the American Society for Testing and Materials (D-3574-11, 2012). The guidelines present clear procedures for testing materials such as foam. In this instance the tests include the Density Test, Indentation Force Deflection Test (IFD) and the Indentation Residual Gage Length Test – specified force (IRGL).

The density test covers determination of the density of uncored foam by calculation from the mass and volume of the specimen. The density value thus obtained applies only to the immediate area from which the specimen has been taken. It does not necessarily relate to the bulk density of the entire moulded pad. The indentation force deflection consists of measuring the force necessary to produce designated indentations in the foam product at 25 and 65 % deflections. The cellular foam products have been traditionally checked for indentation force deflection by determining the force required to effect a 25 % deflection. During standing, on the other hand, the interest is in determining how thick the padding is under the average person. Multiple measurements are called for to meet the requirements of this test method. The force deflection is determined by measuring the thickness of the pad under a fixed force of 4.5 N, 110 N, and additional 110 N incremental increases up to 1320 N. with a 200 +3/–0 mm circular indenter foot.

This determination shall be known as the Modified Indentation Residual Gauge Length and the measurements as the MIRGL values. The detailed description of these tests can be found in chapter 3.

2.4 Electromyography

2.4.1 Introduction

Electromyography (EMG) is a method for evaluating and recording physiological properties of resting and/or contracting muscles. It is used to detect the electrical potential generated by these muscle cells when they contract as well as when they are at rest (Jonsson, 1978). The use of surface electromyography (EMG) in biomechanics is widely known and investigators rely on this tool for assessment of muscle force, muscle fatigue or to help in the study and diagnosis of neuromuscular disorders (Meekins et al., 2008). Modern surface EMG recording techniques have the advantage over needle

EMG of being non-invasive and theoretically, have the advantage of recording over a larger area of one or many muscles. The data recorded may include waveform measurements of voltage, amplitude, frequency, and the relationship of these parameters to force and duration of muscle contraction (Meekins et al., 2008).

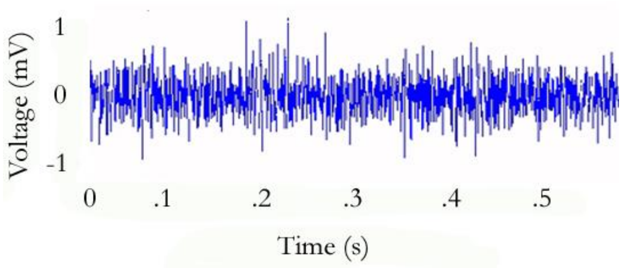
EMG recording is now quite standardised but researchers use different signal parameters in order to obtain specific information. Below is a brief description and relevant methods of signal analysis for this particular research.

2.4.2 EMG detection and recording

An EMG signal is stochastic in nature and can be represented by a Gaussian distribution. The amplitude of the signal can range from 0 to 10 mV (peak-to-peak) or 0 to 1.5 mV (rms) (Chin et al., 2008). Although the frequency of the signal may rise to 15kHz, in practice, the usable range of the signal is limited to 0 to 500 Hz, although the frequencies is mainly found in the 50-150 Hz range. An example of an EMG signal and its corresponding frequency spectrum is represented in Figure 8.

The overall quality of the signal recorded is dependant on two main variables: the signal to noise ratio and on the distortion of the signal (Raez et al., 2006). Electrical noise originates from the electric equipment used and from a number of other sources such as electromagnetic radiation, radio and television transmission, electrical wires, light bulbs and fluorescent lamps, etc. Unfortunately, this noise cannot be eliminated entirely, but it can be reduced using high quality electronic components, intelligent circuit design and construction techniques.

a



b

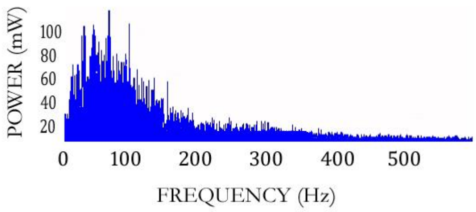


Figure 8 Example of EMG signal and its corresponding frequency spectrum

(a) Multiple, overlapping action potentials due to the concurrent activation of many motor units detected from the right neck extensor muscles during an isometric contraction at 35% maximum voluntary contraction; (b) Frequency spectrum of sEMG signal shown. These figures are actual screen shots taken during data analysis.

One of the methods used to improve the signal to noise ratio is in the care taken to design the most efficient electrodes (Stegeman et al., 2000), but it is the technique used to record the muscle activity that appear to have the greatest potential to reduce noise. In order to eliminate the potentially much greater noise signal from power line sources, a differential detecting configuration is employed by most researchers now. The signal is detected by bipolar montages which measure the electrical activity between two adjacent recording electrodes. Electronic circuitry then subtracts the two signals and amplifies the difference (Roy et al., 2007). As a result, any signal that is common to both detection sites will be removed and signals that are different at the two sites will have a differential that will be amplified thus eliminating the power line noise. Obviously, interactions between the electrolytes in the skin and the metal of the detection surfaces of the electrodes are essential for good recording and this is achieved by preparing the skin, in particular: removing dead dermis from the skin surface.

The amplitude of the sEMG signal is directly proportional to the distance between the detection surfaces (Plastaras et al., 2008), thus the main problem with increasing the distance between the electrodes is a corresponding loss of specificity in the signal. Furthermore, the filtering characteristics of the differential amplification decreases in bandwidth (Basmajian and De Luca, 1985). The compromise generally accepted is to distance the electrodes by typically 1cm (Nishihara et al., 2010).

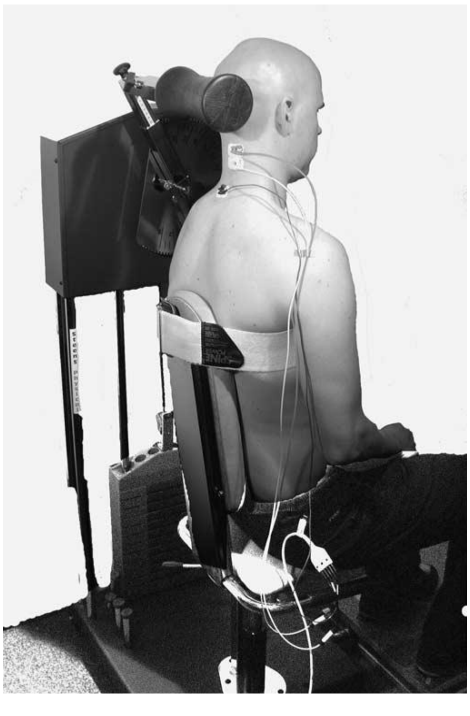


Figure 9 Example of surface electromyography electrodes placement for right neck extensor muscle recording (Gosselin et al., 2004)

The Common Mode Rejection Ratio (CMRR) of the recording equipment, which dictates the measurement accuracy of the differential amplifier, is also important to obtain a good quality sEMG signal. Presently, a CMRR of 32,000 or 90dB is used to suppress extraneous electrical noise even though modern units can achieve 142 dB (Zhang et al., 2009).

Another aspect to consider in sEMG measurements is the input impedance. The input impedance at the junction of the skin and detection surface may range from several thousand ohms to several megaohms for dry skin. While the absolute level of muscle impedance is not a critical factor, the stability in impedance over time and the balance in impedance between electrode sites have a considerable effect on the signal to noise ratio of the EMG signal (Freriks and Hermens, 2000). Unfortunately, by increasing the input impedance, a problem known as capacitance coupling appears at the input of the differential amplifier. De Luca (2002) describes the phenomenon as a small capacitance between the wires leading to the input of the differential amplifier and the power line will introduce a power line noise signal into the amplifier (De Luca, 2002). This phenomenon can be corrected by placing a differential amplifier as close as possible to the detection surfaces of the electrode and is called an “active electrode”. This configuration has the advantage of producing a very low impedance of around 10 ohms. Therefore movement of cable from the output electrodes with generate minimal noise in the amplifier.

Finally, even with the measure described above, there will be some signal contamination. The signal-to-noise ratio can be increased further by filtering between 15-500 Hz (van Boxtel, 2001). High-pass filtering removes low frequency components (typically <10Hz) caused by movement artefacts, while low pass filtering removes high-frequency components thereby avoiding signal aliasing (Ferreira and Lima, 2014).

2.4.3 EMG signal analysis

The raw EMG signal is not usable in its raw form therefore the information contained within the signal needs to be quantified. Various signal-processing methods are applied, with both time and frequency domain approaches used but investigators.

The most common signal analysis routine is to process the raw EMG by performing a linear magnitude Fast Fourier Transform (FFT) followed normalisation of the spectrum (values from 0 to 1). To normalise, the data is divided by the maximum value in volts on the integrated spectrum. The median frequency (MF) appears to be a useful objective measure for evaluating muscle function and fatigue of the cervical musculature (Gogia and Sabbahi, 1990) and is found by determining the frequency at the integrated EMG spectrum returns a value of 0.5 (De Luca, 1993).

2.5 Field dependency and independency

The descriptive concept of "perceptual style" has been a rather popular approach to the recurrent problem in perception of the consistent and significant individual differences exhibited by individuals on any number of perceptual tasks. On the one hand, such an approach has allowed the theorist and researcher to treat the grossly apparent variability of human perceptual behaviour in a somewhat logical and unified manner. However, it has resulted in the introduction into science of new terms or constructs of often questionable utilitarian and even less explanatory value. Even a rather cursory review of the perceptual literature yields a number of proposed "styles" or modes of perceptual functioning which operationally serve to differentiate individuals by the manner in which some particular stimulus event is perceived. As examples of some of these styles, Bartlett (Bartlett, 1932) proposed the distinction between "confident" vs "cautious perceivers", between "levelers" vs "sharpeners," Altrocci (Altrocci, 1961) between "repressors" vs "sensitisers," Zegers and Murray (Zegers and Murray, 1962) between "high perceivers" vs "low perceivers," Silverman et al., (Silverman et al., 1969) between "augmenters" vs "reducers," and Elithorn and Barnett (Elithorn and Barnett, 1967) and Kennedy (Kennedy, 1970) between "narrow" vs "broad" band-pass individuals. The most popular of the perceptual styles since the late sixties however, has unquestionably been that of "field-dependent" vs "field independent" individuals, originated and largely developed by Witkin and his co-workers (Witkin and Asch, 1948a, Witkin, 1949, Witkin, 1950, Witkin, 1965, Witkin et al., 1967, Witkin et al., 1968).

2.5.1 The rod and frame test

Operationally, the perceptual style of "field dependency-independency" advanced by Witkin refers to the continuum of individual differences, ranging from extreme field-independency to extreme field-dependency, demonstrated on certain perceptual tasks, most commonly, the Rod-and-Frame Test (RFT). In its basic form, the RFT requires the individual to directly or indirectly adjust a movable rod to the true vertical position while the rod itself is located in a separately tilted frame. Individuals have been found to differ widely but reliably in their ability to ignore the distracting context of the "crooked" frame and set the rod to a truly vertical position (Witkin and Asch, 1948a, Witkin and Asch, 1948b, Witkin and Oltman, 1967). Concerning specific coefficients of reliability with the RFT, correlation between the even items and odd items of the RFT of 0.92 and 0.89 were reported (Gardner et al., 1960, Liu and Chepyator-Thomson, 1988) although Liu found reliability of 0.78 in children under 17 years of age (Liu and Chepyator-Thomson, 1988). Furthermore, the invariance of the individual's RFT performance under various experimentally manipulated conditions of changing sets, instructions, familiarity with apparatus, and practice has been demonstrated for some time (Olson et al., 1965, Guillot and Collet, 2004, Witkin and Oltman, 1967).

The RFT has been generally interpreted therefore as an indication of an individual's ability to ignore; that is, to function perceptually in the presence of a misleading, distracting, or even conflicting context (Witkin and Wapner, 1950, Witkin, 1954, Gardner et al., 1960, Olson et al., 1965). Those individuals who are relatively "good" at such tasks, who can adjust the rod close to true vertical have been termed "field-independent" (FI). Those who exhibit difficulty with the test, who are strongly influenced by the misleading visual surround, have been termed "field-dependent" (FD). It is on the basis of this measure that most of the further work with field dependency has been conducted, although some other somewhat related measures such as the Embedded Figure Test and the Draw-A-Person Test have also been employed, but much less frequently (Witkin et al., 1954; Adevai et al., 1968b).

There are a number of commercial versions of the RFT available which differ from one another in a number of respects, such as the size of rod and frame, distance of target (rod) from the subject, and illumination level, etc. These commercial RFTs can also differ in being experimenter-operated or subject-operated. Although the correlation between the two is reportedly very high at $r = 0.83$, (Adevai and McGough, 1968) it has been suggested as a possible contributing cause to discrepant findings in at least one instance (Vaught and Solomon, 1970). In 1968, Oltman introduced a "portable" RFT apparatus in contrast to the stationary type originally employed by Witkin (Oltman, 1968). In general, the correlations between the portable and stationary forms of the RFT have been relatively high $r \geq 0.74$ (Kato et al., 1965, Morris, 1967), however, a much lower correlation, $r = 0.46$, has also been reported (Vaught and Solomon, 1970). Although it is likely that this rather low correlation between the two RFTs was due to some form of confounding factor such as lighting, it does clearly demonstrate the care that the experimenter must take in administering the RFT in order to reduce external biases or cues and thereby protect the integrity of the test. Along these same lines, influences such as participant's head position and instructional effects are certainly possible factors which can serve to reduce the traditional RFTs validity and reliability.

It took 40 years or so before a computerised version of the RFT was developed. In 2003, a 3-dimentional RFT system comprised of a screen with a fixed semi immersive display was introduced. The results compared well with previous mechanical systems but it still needed dedicated experimental space

(Reger et al., 2003). In 2005, Bagust programmed a computerised version of the test (Bagust, 2005) which became the first practical digital version of the classic RFT. Subjects sat in front of a computer wearing video goggles and controlled the rotation of the rod by pressing mouse buttons. Validation of the sequence was performed by pressing the space bar. Lack of standardisation in previous studies makes it difficult to compare earlier results with the computerised version but the results overall were comparable in direction and amplitude (between 1^0 to 6^0) with previously published data.

Isableu et al., (2008) reported that participants using a different computerised RFT showed significantly larger rod deviations compared to the mechanical RFT, and although both methods correlated they shared a small amount of common variance. They suggested that the smaller errors observed with the computerised system might be due to the participants aligning the rod using the rods pixilation on the computer screen or on the video goggles. Bagust overcame this by replacing the rod by two dots representing the ends of a line (Figure 10). There were no significant differences with previous studies using a mechanical device which suggests that replacing the rod/line with dots improved the reliability of the tests.

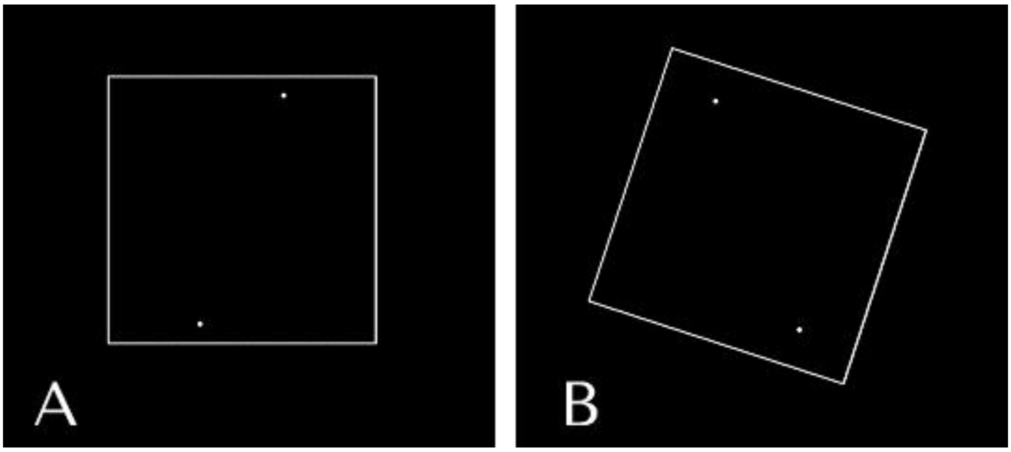


Figure 10 Computer screen capture of test from the C-RFT^{dot} (Docherty and Bagust, 2010)
A Dots with frame (: frame^0) B Dots with frame tilted: (frame $^{+18}$)

One of the main disadvantages of the computerised RFT is that subjects may gain proprioceptive feedback by not only touching the keyboard and the mouse but also by having their arms resting on the table. The current project required the development of a procedure in which the participants took the test in the standing position and controlled the dots and validated their selection by using a handheld computer mouse. In other words, the participants took the test standing without their body touching any external structure.

Recently, the computerised Rod and Frame Test has been used to study effects of neck pain on the subjective visual vertical or field dependency (Docherty et al., 2012, Uthaikhup et al., 2012, Panichaporn et al., 2013). Overall, the studies have shown that the score of participants suffering from chronic neck pains significantly fell outside the reference range of errors and a subgroup of patients, characterised by higher neck pain disability indices or elderly participants, were identified who demonstrated higher than expected errors for both SVV and SVH.

2.5.2 Field dependency and physical activity

Studies have investigated the relationship of field dependence-independence to open and closed sports (i.e. if field dependence is an advantage for participants in open-skill-dominated sports, and field independence is an advantage for participants in closed-skill-dominated sports). Sports with a preponderance of closed skills refer to sports that take place in relatively predictable and/or stable environments, such as swimming, track and field. Open skill sports are those that involve relatively unpredictable and changeable situations such as ball games (Liu, 2003). Athletes that base their skills on internal receptors or proprioception do not rely on their environment for stability and generally perform better in closed-skill sports or activities.

Ashfari (2011) suggested that in view of the different information-processing requirements for closed- and open-skill-dominated sports, field independent athletes could have an advantage when participating in sports with mainly closed skills, and conversely, field dependence could be an advantage for participants in sports with a preponderance of open skills (Afshari et al., 2011). The difference however is less clear during complex open or closed motor skills (Guillot and Collet, 2004).

2.6 Subjective perception of balance, fatigue

Participants in experiments involving the control of balance often report postural instability or unsteadiness whilst their posturographic results might be within normal limits (Nardone et al., 2010). This is observed in patients suffering from neurologic disorders such as Parkinson's disease where patients feel unsecure in the standing posture although the resulting sway area and sway path during posturography is found to be in the normal range (Vaugoyeau et al., 2011). On the other hand, people affected by peripheral neuropathies can hardly be clustered in a single group according to the posturographic recordings and to the self-reported feeling of unsteadiness. In fact, they report disturbing unsteadiness or complain of hazardous stance, and are prone to falls but, in some cases they do not show abnormally large posturographic recordings, although in other cases they do (Schieppati et al., 2003). There is as yet no indication of congruence between absolute body sway and perception of it. There has been a focus for some time now on qualitative investigation in medicine bringing with it a tendency to model qualitative research along quantitative lines (Schieppati et al., 1999). Examples are self-evaluation scales or inventories, designed to be filled in by the participant or patient without the intervention of the examiner and such scales have been shown particularly useful in approaching patients reporting dizziness or disturbance of balance (Major et al., 2013). Relations between components of balance function and self-perceived unsteadiness have already been assessed in vestibular patients and elderly subjects (Kurre et al., 2012). However, accurate evaluation when bringing together the perception of stability during a postural task, such as quiet upright stance, and the real steadiness recorded with a computerised posturography is still lacking. For this reason we have used in this project the scale used reproduced the method that assessed the subjective perception of balance during a posturographic study (Schieppati et al., 1999).

The subjective perception of exertion or fatigue during a muscle contraction has been well documented (Borg, 1990, Enoka, 2012, Kluger et al., 2013). In 1982, Borg presented a magnitude estimation scale where the scale would increase linearly with the intensity of effort which would permit to indicate the degree of physical strain (Borg, 1982). Although other ratings of perceived effort scales are used, such as the OMNI-Cycle scale (Guidetti et al., 2011), the Borg scale is still the more frequently use scale due to its ease of use (Aamot et al., 2013, Fontes et al., 2013, Simonsick et al., 2014, Diniz et al., 2014).

Chapter 3 - Equipment

This chapter introduces the equipment used in this research, the key functions of which were to 1) produce physiological alterations to healthy participants and 2) record such effects.

A force platform is a measuring instrument that records the ground reaction forces generated by a body standing on it, and was used here to quantify balance and centre of pressure change. In combination with the force platform, an electromyographic (EMG) system was used to record the electrical activity produced by muscle cells as they were activated, such as during the neck muscle fatigue protocol used in the experiments.

Video goggles used were used as an alternative to a computer screen. The inclusion of peripheral eye cups limits further environmental distractions such as light or movement.

One of the objectives of the research was to determine if and how balance can be altered by decreasing proprioceptive feedback. The inclusion of foam pads was a key element of those experiments, and this chapter also includes a detailed description of the work carried out to fully characterise their properties.

Lastly, the support structure used to apply the neck fatigue protocol during the experimentation is described.

A summary of the equipment used and its role in the research is provided in Table 2.

Table 2 Equipment used in this project

Equipment	Function
Force platform	To quantify balance and measure changes in centre of pressure
Electromyography recording system	To record electrical activity of muscle cells
Video goggles	To act a surrogate computer screen and minimise external distractions
Foam pads	To decrease stability during posturography
Frame and pulley system	To apply the neck muscle fatigue protocol

3.1 Force platform

The force platform used in these projects was the QPS-200 from Midot Medical Technology (Gan Ner, Israel) (Figure 11). It is a portable force plate consisting of four electronic weighing plates set in a rectangular position. The QPS-200 records data using a 200 Hz sampling rate and the filter frequency is set at 0.5 Hz. The software provided with the platform is the Posture Scale Analyser which returns velocity, and centre of pressure values.

Figure 11 Force platform: QPS-200, and software; Posture Analyser
From Midot Medical Technology, 276, Irus Street, Gan Ner, Israel, 19351.

3.1.1 Force platform accuracy

Method

The accuracy of the force platform was assessed against standard disks of known mass. Seven types were used (2.5 kg, 5kg, 10 kg, 12.5 kg, 15 kg, 20kg, 25kg) placed in 22 different combinations on the force platform (Table 3), and the corresponding masses measured by the force plate recorded and saved in an Excel spreadsheet. An intra-class correlation coefficient was performed to analyse the data. Statistical analyses were performed using SPSS Statistics 17.0

Results

The results of the values returned from the force platform are compared to the actual masses values in Table 3.

Table 3 Comparison between applied and recorded weights

Test number	Applied mass (kg)	Displayed mass (kg)
1	2.5	2.5
2	5	5.05
3	10	9.075
4	12.5	12.5
5	15	15.05
6	20	20
7	25	25.025
8	30	30.02
9	35	35.06
10	40	40.05
11	45	45.07
12	50	50.06
13	55	55.03
14	60	60.09
15	65	65.08
16	70	70.08
17	75	75.06
18	80	80.1
19	85	85.12
20	90	90.1
21	95	95.09
22	100	100.1

Statistical analysis

An intra-class correlation coefficient was computed to assess the relationship between the applied and measured values (Table 4). There was a correlation between the two variables (r=.998, n=22, p=.001). A scatterplot summarises the results in Figure 12.

Table 4 Intra-class correlation coefficient of force platform accuracy

Correlations

		Discs_mass_kg	Displayed_mass_kg
Discs_mass_kg	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.001
	N	22	22
Displayed_mass_kg	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.001	
	N	22	22

**. Correlation is significant at the .01 level (2-tailed).

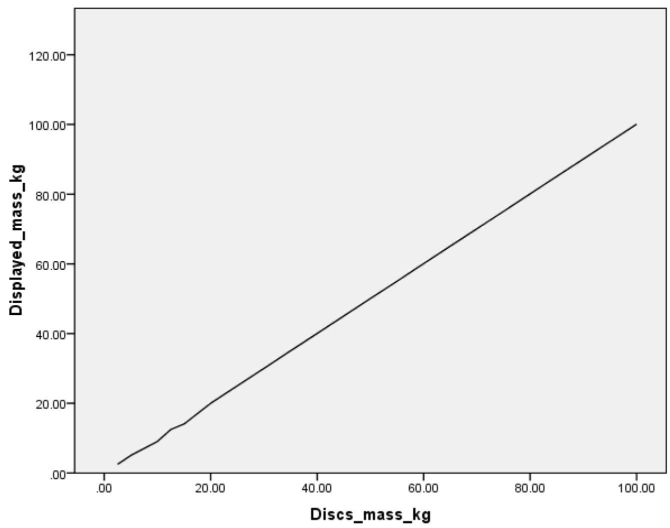


Figure 12 Correlation scattergram of free weights vs displayed mass

Conclusion

The force platform was showed accurate when measured with factory produced weight disks.

3.1.2 Force platform reliability

Test-retest experiments were carried out to assess the repeatability of the force platform.

Method

Again seven different weights (2.5 kg, 5kg, 10 kg, 12.5 kg, 15 kg, 20kg, 25kg) were placed in 22 different combination on the force platform. The order in which the weights were placed on the platform was determined randomly using a random sequence generator (http://www.random.org/sequences/). The corresponding weight measured by the force plate recorded and saved in an Excel spreadsheet. The procedure was repeated twice, and statistical analysis was performed to analyse the data using SPSS Statistics 17.0).

Results

The results for each of the 22 different configurations of random sequence1 and sequence 2 are presented in Table 5.

Statistical analysis

An intra-class correlation coefficient was computed to assess the relationship between the two repeated measures of factory produced free weights returned by the force platform (Table 6). There was a correlation between the two variables ($r=1.0$, $n=22$, $p<.0001$). A scatterplot summarises the results (Figure 13).

Conclusion

The force platform was showed reliable when measured with factory produced weight disks.

Table 5 Number allocation to free weight masses

Mass	Allocated number	Random sequence 1	Results sequence 1	Results sequence 2
2.5 kg	1	19	85.1	85.1
5kg	2	21	95.09	95.08
10kg	3	6	20.02	20.02
12.5kg	4	17	75.03	75.08
15kg	5	7	25.02	25.02
20kg	6	18	80.05	80.04
25kg	7	13	55.03	55.07
30kg	8	10	40.06	40.01
35kg	9	11	45.05	45.03
40kg	10	2	5.05	5.06
45kg	11	4	12.51	12.54
50kg	12	20	90.09	90.09
55kg	13	3	10.01	10
60kg	14	15	65.08	65.07
65kg	15	9	35.06	35.04
70kg	16	5	15.01	15.01
75kg	17	14	60.07	60.03
80kg	18	22	100.1	100.09
85kg	19	8	30.02	30.05
90kg	20	12	50.06	50.05
95kg	21	16	70	70.08
100kg	22	1	2.5	2.51

Table 6 The intra-class correlation coefficient of platform reliability

Correlations

		Random Sequence 1	Random Sequence 2
Random_sequence_1	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.0001
	N	22	22
Random_sequence_2	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.0001	
	N	22	22

**. Correlation is significant at the 0.01 level (2-tailed).

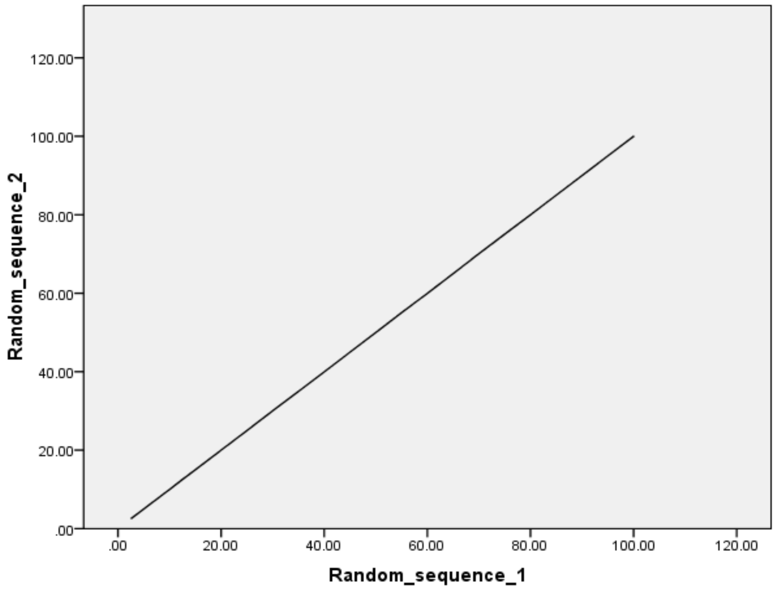


Figure 13 Test re-test correlation scattergram of the force platform

3.2 Electromyography acquisition system

Description

The data acquisition unit used was the iWorx model: IWX/214 (Fig .14). The isolated inputs of channels 1 and 2 (CH1 & CH2) of the unit have built-in biopotential amplifiers that receive electrical signals through a standard ECG cable. The mode controls for these channels invoke the appropriate filter settings for recording electromyograms.

Figure 14 Front and rear panels of IWX/214

3.2.1 Validity

Method

Validity of the electromyographic acquisition system (Figure 15) was measured against a factory calibrated signal generator (Figure 16) (TG1010A, Thurlby-Thandar Instruments, Huntingdon, Cambs, UK). The voltage was set to 5 millivolts (mV). High and low pass filters was set to 3 – 10 KHz and sampling was set at 2KHz. The effective frequency recording range for surface electromyography is between 25 and 500 Hz. The sampling frequency is thus twice the maximal Nyquist rate. Therefore, 20 different frequencies from 25 to 500Hz at 25 Hz intervals were produced by the signal generator and recorded with the EMG acquisition system during five seconds.

A Fast Fourier Transformation (FFT) was performed and the acquired raw data after the signal was recorded. The frequencies recorded in Hertz (Hz) were recorded in an Excel spreadsheet. An intra-class correlation coefficient was performed to analyse the data (SPSS Statistics 17.0).

A

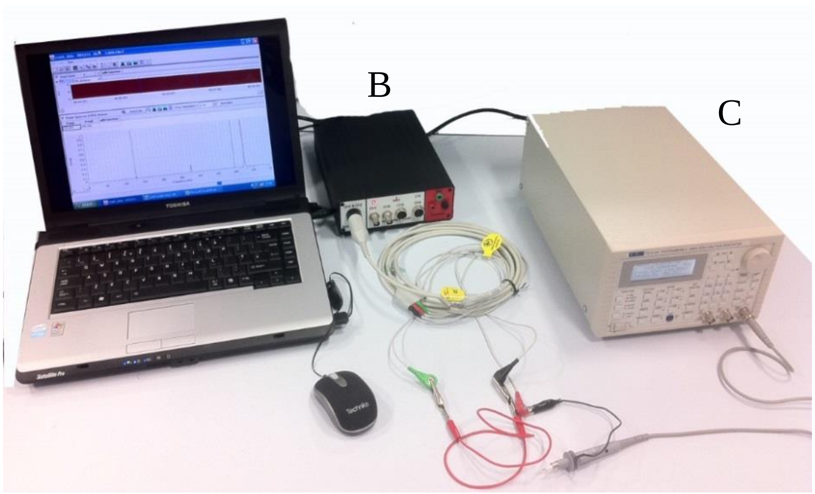


Figure 15 Validation setup

A. Laptop with acquisition software. B. iWorx unit with EMG recording leads. C. TG1010A Programmable 10MHz DDS Function Generator.

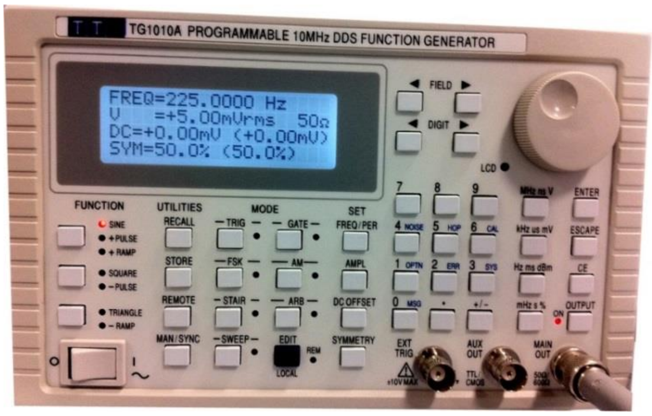


Figure 16 TG1010A Programmable 10MHz DDS Function Generator
An example of generated sine wave, at 225 Hz frequency produced at 5mV

Results

An intra-class correlation coefficient was computed to assess the relationship between the frequencies produced by the factory calibrated frequency generator and the corresponding frequencies recorded by the iWorx system. There was a correlation between the two variables ($r=1.0$, $n=20$, $p<.0001$). Statistical analyses were performed using SPSS Statistics 17.0

Conclusion

The iWorx EMG recording system showed accuracy when measured against a digital signal generator.

3.2.2 Reliability

Test-retest experiments were carried out to assess the reliability of the electromyographic recording system.

Method

Twenty different frequencies from 25 to 500Hz at 25 Hz intervals were generated by the signal generator (TG1010A, Thurlby-Thandar Instruments, Huntingdon, Cambs, UK) and recorded with the EMG acquisition system (iWorx Systems, Inc., Dover, NH). The voltage was set to 5 millivolts (mV). High and low pass filters was set to 3 – 10 KHz and sampling was set at 2KHz.

The effective frequency recording range for surface electromyography is between 25 and 500 Hz. Therefore, twenty different frequencies from 25 to 500Hz at 25 Hz intervals were produced by the signal generator and recorded with the EMG acquisition system during five seconds (Table 13). The order in which the signals were generated was determined using a random number generator (http://www.random.org/sequences). The procedure was repeated twice. A Fast Fourier Transformation (FFT) was performed after the signal was recorded. The frequencies recorded in Hertz (Hz) were recorded in an Excel spreadsheet. . An intra-class correlation coefficient was performed to analyse the data (SPSS Statistics 17.0).

Statistical analysis

An intra-class correlation coefficient was computed to assess the relationship between repeated generated frequencies produced by the factory calibrated frequency generator and recorded by the iWorx system. There was a correlation between the two variables ($r=1.0$, $n=20$, $p<.0001$). A scatterplot summarises the results. Statistical analyses were performed using SPSS 17.0

Conclusion

The EMG recording equipment was shown to be reliable.

3.3 Video goggles

The C-RFT^{dot} performed in this thesis required the use of video goggles. The model chosen was the X-Men goggles made by Prober (Shenzen EOS Electronic Co. Hong Kong, Figure 19, with specifications in Table 7, Figure 17). The goggles connected to the laptop via a video RS-232 port.

Table 7 Video goggles specifications

Brand name	Prober
Model	XMen
Manufacturer	Shenzen EOS Electronics Co, Hong Kong)
Virtual screen @2m distance	1.5 -2m
Video system	NTSC/PAL auto switch
Internal memory	2Gb
Calibration	Factory calibrated

Figure 17 Prober video goggles

3.4 Foam pads

The properties of the pads were measured using three tests based on ASTM test D-3574-11 (Figure 18) (D-3574-11, 2012). Uniaxial compression was achieved using a screw driven test machine (LR 100K, Lloyds Instrument, Bognor Regis, UK) with a 100 kN load cell. The press was remotely controlled via a desktop computer running Nexygen software (Lloyds Instrument, Bognor Regis, UK). Four foam pads were obtained from three sources: 1) rehabilitation material supplier, 2) online foam shop and 3) upholstery high street shop (Figures 19, Table 11). The pads had a size of 480×480mm, with the exception of the rehabilitation balance pad which had a smaller size of (440×400mm). The atmospheric pressure in the laboratory was 1015 hPa and the temperature was 22^{0}C.

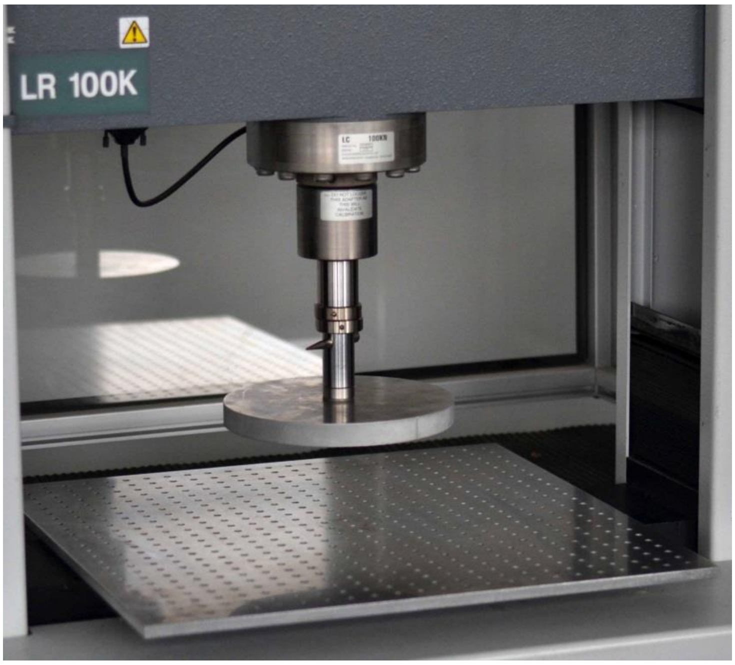


Figure 18 Screw-driven test machine (LR 100K, Lloyds Intrument, Bognor Regis, UK) with a 100kN load cell showing the 203mm indenter foot above the perforated horizontal support plate

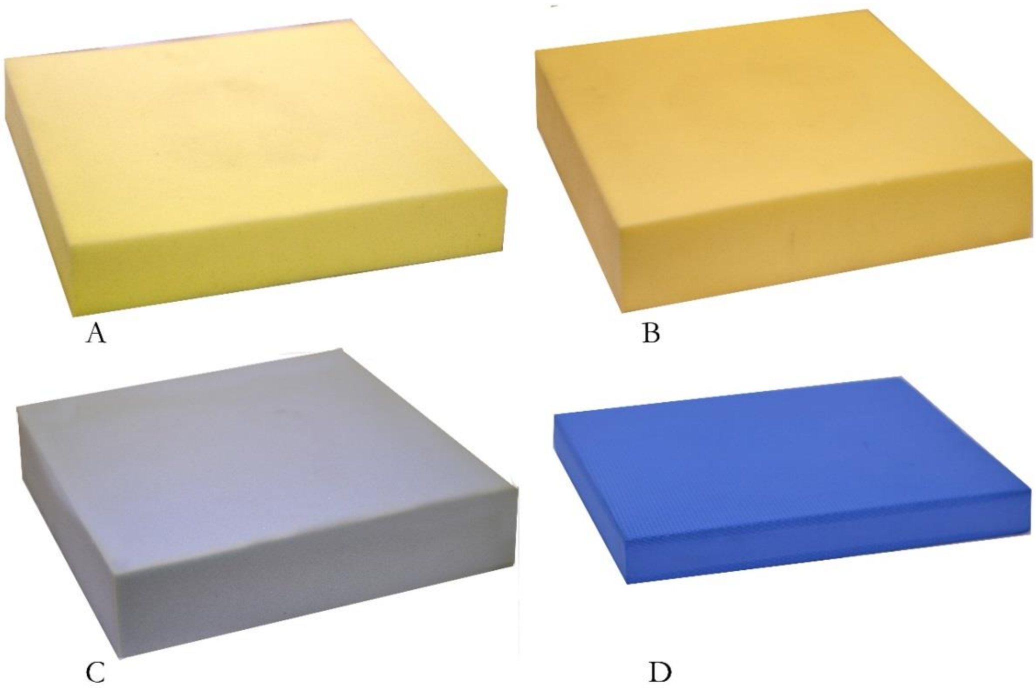


Figure 19 A. Memory foam 75mm; B. Memory foam 100mm; C. Upholstery foam 100mm; D. Balance pad 50mm

3.4.1 Test A: Density measurement

The density of the uncored foam was calculated from the mass and volume of each specimen. The pad's dimensions (m^3) were measured with the use of a millimetric measuring tape. The mean mass (kg) was recorded as the average of five measurements with an electronic scale (± 1g) (Model 1089 BKWHDR, Salter, Hamburg).

The density was calculated by the formula:

$$\text{Density} = M / V$$

where, M = mass of specimen (kg), and V = volume of specimen (m^3)

3.4.2 Test B: Indentation force deflection test (IFD)

Based on ASTM D-3574-11, this test consisted of measuring the force necessary to produce a predefined indentation in the foam. A flat circular indenter with a 203 mm diameter foot was used to apply a load on the specimen which was supported on a level horizontal plate that was perforated with approximately 6.5 mm holes on approximately 20mm centres to allow rapid escape of air during the tests. From the data obtained, the modulus of elasticity (kPa) was calculated for each specimen with the following formula:

$$E = \frac{\sigma}{\epsilon} = \frac{\frac{F}{A_0}}{\frac{\Delta L}{L_0}} \quad {}^{N}/_{m^2}$$

where:

E is the Young's modulus (modulus of elasticity)

σ is the stress applied on the pad

ε is the strain measured from the application of σ

F is the force exerted on the foam pad

A_0 is the original cross-sectional area of the indenter through which the force is applied

ΔL is the amount by which the height of the pad changes

L_0 is the original height of the pad.

Figure 20 Control panel during Indentation force deflections test showing a 219.82N compression load and a deflection (Extension on the panel) of 76.7mm

Procedure

The specimen was placed such that the indenter was in the centre of the apparatus' supporting plate. The area to be tested was preflexed twice by lowering the indenter's foot to a total deflection of 75% of the full part thickness at a rate of 250 ± 25mm/min (Table 8). The specimen was allowed to rest 6 ± 1 min after the preflex. The indenter was then brought into contact with the specimen by applying a 4.5 N load to the indenter's foot. The specimen was further indented at a rate of 50±5 mm/min to a displacement equal to 25% of the original thickness. The force was then adjusted to retain this displacement for 60±3s at which point the force measurement was recorded and simultaneously displayed in real time on the computer screen and on the press' control panel (Figure 22). Without unloading the specimen, the deflection was increased to 65% deflection allowing the force to drift while maintaining the 65% deflection and again the force was recorded after 60±3s (Table 9).

Table 8 Nexygen preflex command sequence input for 100mm thickness foam sample

```
Stage [80mm], [250mm/min]
MarkerNow ("Take extension reading")
StageHold [80mm],[250mm/min],[5s]

Stage [1mm], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [1mm],[50mm/min],[180s]

Stage [80mm], [250mm/min]
MarkerNow ("Take extension reading")
StageHold [80mm],[250mm/min],[1s]

Stage [1mm], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [1mm],[50mm/min],[360s]
```

Table 9 Nexygen indentation force deflection test input sequence

```
Stage [4.5n], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [4.5],[50mm/min],[10s]

Stage [25mm], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [25mm], [50mm/min],[60s]

Stage [65mm], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [65mm], [50mm/min],[60s]
```

3.4.3 Test C: Modified indentation residual gage length test – specified force (MIRGL)

The traditional "indentation residual gage length" test force (IRGL) used to measure the thickness of the pad under a fixed force of 110N and 220N on a 203 mm diameter circular indenter foot. However, these loads were not sufficient to represent the force of an adult standing on the foam pads. For this reason, the ASTM method was modified to use fixed loads of 110N, 220N 330N, 440N, 550N, 660N, 770N, 880N, 990N, 1100N, 1210N and 1320N. Furthermore, we tested the materials with two indenter sizes: 203 mm diameter and 406 mm diameter (Figure 21).

Procedure

The specimen was preflexed twice with a 330N force applied at 200±20 mm/min and then allowed to rest after load removal 180 ± 5 sec.

The deflection was recorded after the application of 110N applied for 60 ± 3 sec. The load was then increased up to 1320N in steps of 110N, again holding for 60 ± 3 sec at each load increment. The procedures were repeated a second time with a 406 mm diameter indenter. The modified indentation residual gage length input sequence is shown in Table 10.

Table 10 Nexygen modified indentation residual gage length test input sequence

```
Stage [4.5n], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [4,5],[50mm/min],[10s]

Stage [110N], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [110N],[50mm/min],[60s]

Stage [220N], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [220N],[50mm/min],[60s]

Stage [330N], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [330N],[50mm/min],[60s]
.

.

.

Stage [1100N], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [1100N],[50mm/min],[60s]

Stage [1210N], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [1210N],[50mm/min],[60s]

Stage [1320N], [50mm/min]
MarkerNow ("Take extension reading")
StageHold [1320N],[50mm/min],[60s]
```

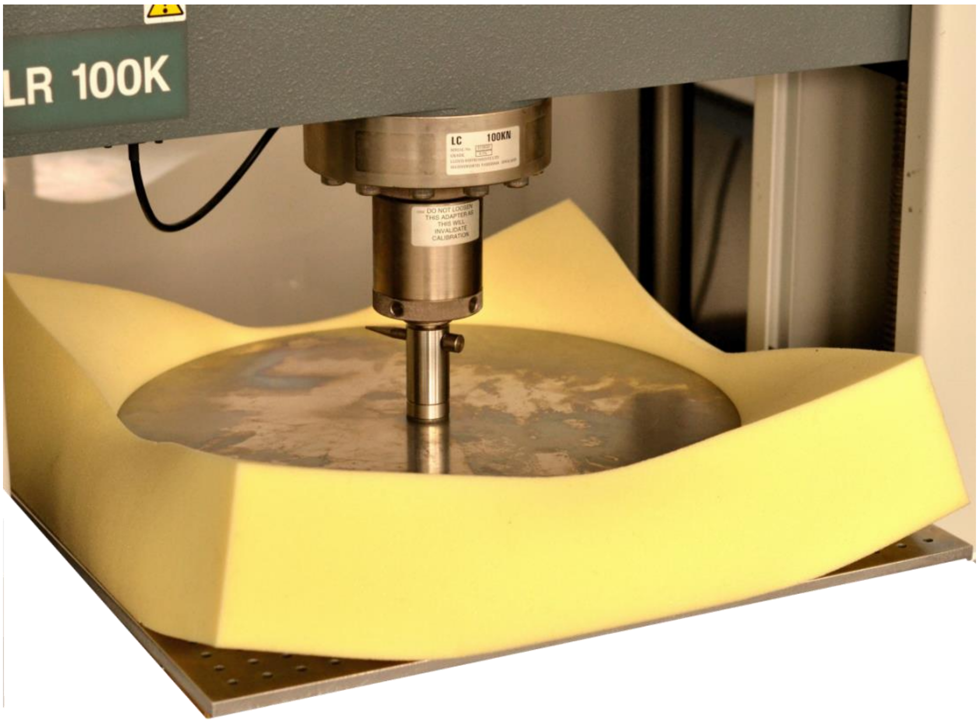


Figure 21 Modified indentation residual gage length test showing the 100mm memory foam sample compressed by the 406mm indenter

3.4.4 Results

Table 22 summarises the foam pad samples characteristics including the manufacturer, model, type of foam, size, volume, mass density and modulus of elasticity. The density of the tested samples varied from 63.5 kg/m^3 for the Vitafoam memory foam down to 38.6 kg/m^3 for the Airex balance pad. Conversely, the memory pads had a value of E of 16.1 kPa whilst the balance pad's E was 217.9 kPa (Table 15).

The indentation force deflection test showed that memory foam pads necessitated much lower loads in order to produce a deflection of 25 and 65% of their original height. Conversely, pads with a larger E necessitated a larger force in order to achieve the same deflection as seen in Table 16.

Table 11 Foam sample specification

Manufacturer	Model	Type	Size (mm)	Volume (m^3)	Mass (kg)	Density kg/m^3	*E* kPa
Vitafoam Ltd UK	Memory Foam Vasco 40 MF-75mm	Urethane Open-Cell	480 x 480 x 75	0.01728	1.07	63.5	16.1
Vitafoam Ltd UK	Memory Foam Vasco 40 MF-100mm	Urethane Open-Cell	480 x 480 x 100	0.02304	1.46	63.5	16.1
Vitafoam Ltd UK	Reflex 35 M Ups-100mm	Urethane Open-Cell	480 x 480 x 100	0.02304	0.86	37.3	44.9
Airex AG Speciality Foams Industrie, CH	Balance Pads BP-50mm	Polyurethane Closed-cell	440 x 400 x 50	0.0088	0.34	38.6	217.9

The density was calculated by dividing the mass by the volume. *E* was measured using the data provided by the indentation force deflection test when specimen was compressed at 25% of its original length.

Table 12 Indentation force deflection test (IFD)

	203mm diameter indenter	
	Load (N) at 25% thickness reduction	Load (N) at 65% thickness reduction
MF-75mm	65.2	169.5
MF-100mm	74.7	200.6
Uph-100mm	181.3	550.7
BP-50mm	880.9	4861.2

The deformations of the foam pads during the MIRGL test using the 203mm indenter were non-linear with the exception of the balance pad which showed linearity throughout the range of loads applied (Figure 22, Table 13). Furthermore, both memory foam and upholstery pads were compressed to more than 75% of their original length when a load corresponding to an average male's weight of 770N was used. The 406mm indenter did not alter the memory foam's linearity during the MIRGL test, in contrast to the upholstery pad which showed a linear deformation from 660N compression onwards with this larger indenter (Figure 23, Table 13).

Table 13 Modified indentation residual gage length test - specified force (MIRGL) for the 203cm and 406cm indenters.

	203mm indenter				**406mm indenter**			
	MF75	**MF100**	**UPH**	**BP**	**MF75**	**MF100**	**UPH**	**BP**
110N	38.7	50.2	7.38	3.05	6.5	3.8	6.0	0.3
220N	59.7	76.4	23.3	3.99	10.1	12.4	6.7	0.6
330N	61.1	84.5	44.1	5.12	34.8	34.7	7.4	1.0
440N	64.6	88.3	59.1	6.42	43.8	54.2	8.5	1.4
550N	65.1	90.6	67.9	7.62	50.7	59.1	10.9	1.8
660N	66.3	92.3	73.3	9.17	53.5	66.4	14.8	2.2
770N	68.2	93.5	77.0	10.5	56.5	69.4	30.2	2.6
880N	69.5	94.6	79.3	11.76	57.6	71.9	39.0	3.1
990N	70.3	95.3	83.5	12.7	59.6	73.3	48.7	3.5
1100N	71.6	96.2	86.3	13.9	60.4	74.8	57.4	4.0
1210N	72.4	96.9	87.5	14.9	61.5	76.5	63.4	4.4
1320N	73.1	97.3	88.6	15.9	62.1	69.8	69.8	4.9

Values in mm. MF75: memory foam 75mm thickness; MF100: memory foam 100mm; UPH: upholstery foam 100mm; BP: balance pad 50mm.

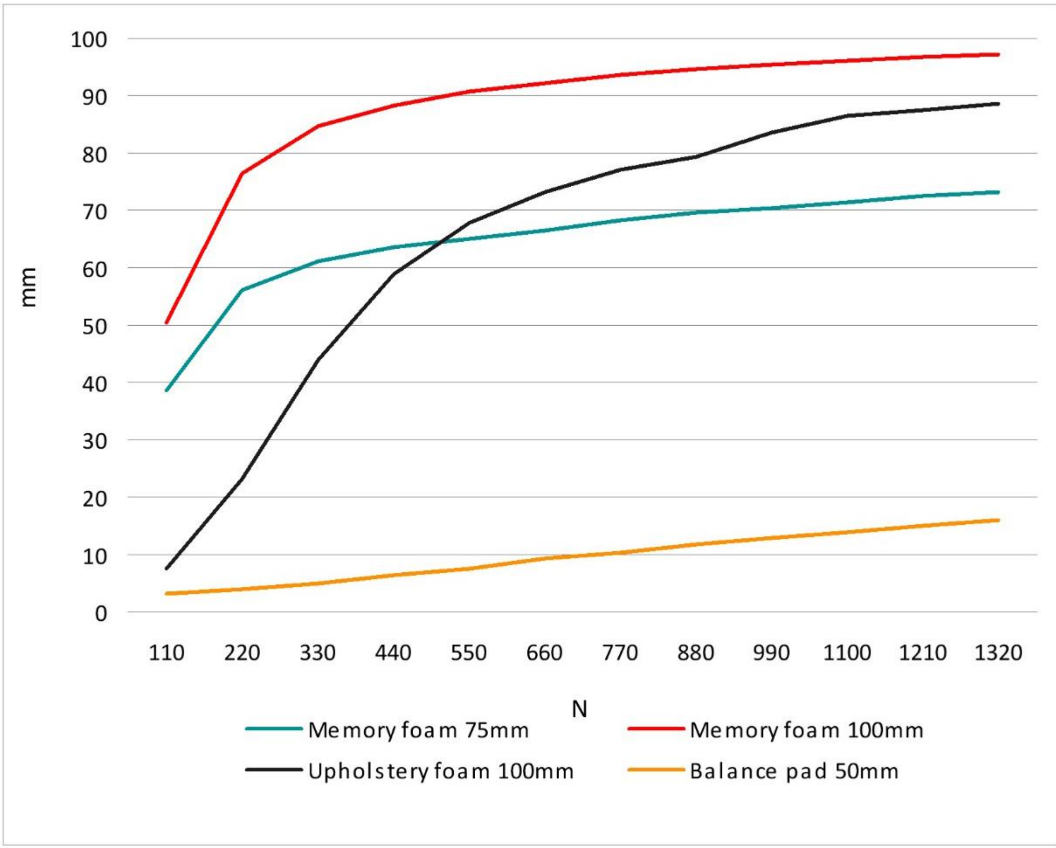


Figure 22 Modified indentation residual length test using the 203mm indenter foot

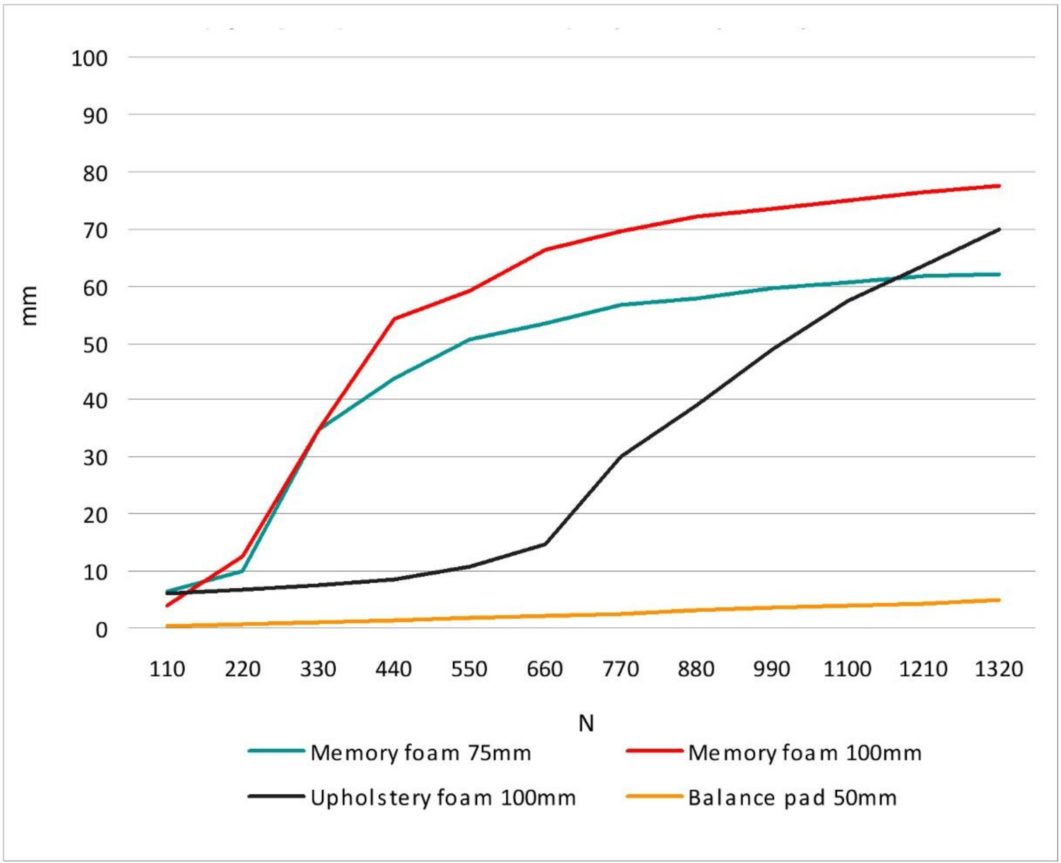


Figure 23 Modified indentation residual length test using the 406mm indenter foot

Figures 24 and 25 show the stress strain curves with the 203mm indenter and 406 indenter respectively. The similar pattern of deformation, as seen in the MIRGL (Figures 20, 21), where the balance pad shows linear deformation with both indenters although higher stiffness is observed with the 406mm indenter. The upholstery pad also shows a linear stress-strain curve from around 35 kPa load when the 406mm indenter is used. The memory foam pads showed no linearity and deformed maximally with minimal strain both with the 203mm and 406mm indenters.

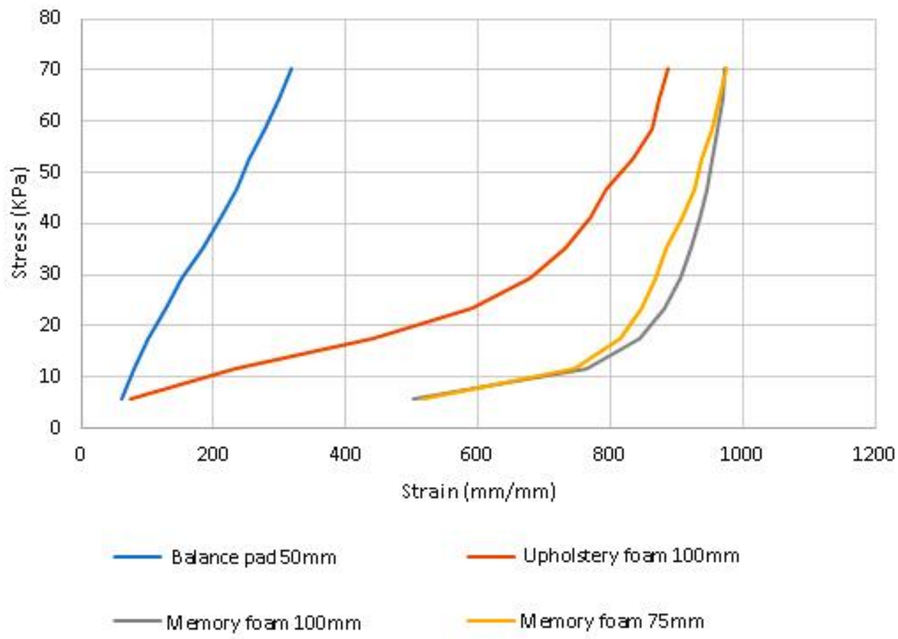


Figure 24 Stress (kPa) vs Strain (mm/mm) measured using the 203mm indenter

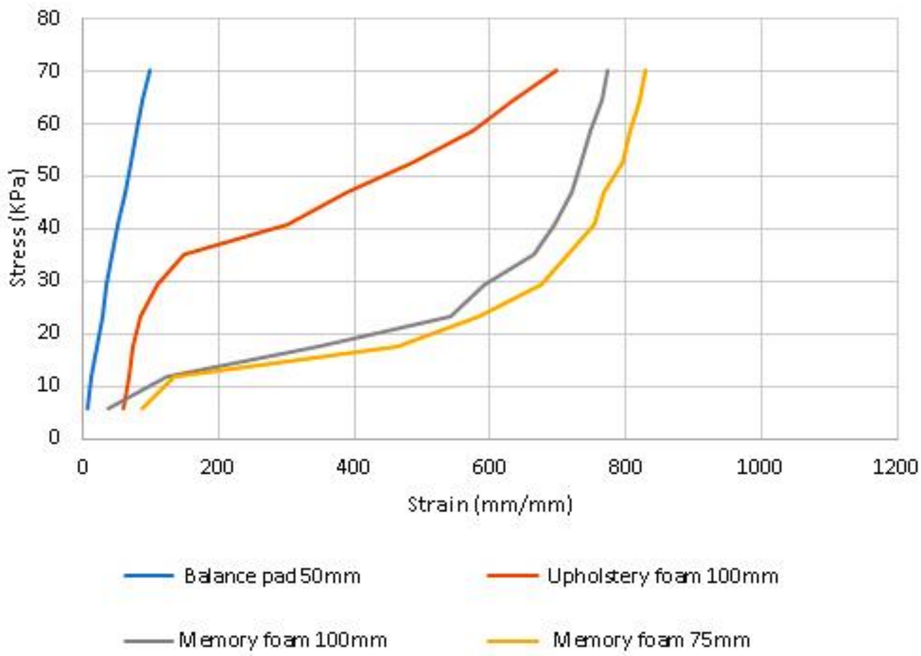


Figure 25 Stress (kPa) vs Strain (mm/mm) measured using the 406mm indenter foot

3.4.5 Summary of foam pads characteristics

Through compression testing of different types of open cell foams using ASTM standard D-3574-95, this study has shown that the foams' effective stiffness increases as the diameter on the indenter increases. Also, the foam pads, with the exception of the balance pad and the upholstery foam with the 406mm indenter, did not show linear deformation throughout the range of loads used in the MIRGL with both the 203mm and 406mm indenters. Both memory foam pads failed to resist the compression at relatively low loads which suggested they would not provide sufficient resistance to compression during posturography for healthy adult participants. Their compression slopes during the MIRGL clearly show a trend towards asymptotic displacement beyond 220N for the memory foam and beyond 660N compression for the mono-layer upholstery foam. Non-linear stress-strain relationships were observed due to the changes in the foam geometry at high strains.

3.5 Neck muscles contraction frame and pulley system

In order to standardise the fatigue protocol, a custom apparatus was built (Figure 26). The apparatus consisted of a rectangular cage of 2.1 m height by 1.2 m length and 1.2 m wide. The welded frame was made of mild steel angle of 3×3cm. Additional rigidity was achieved by welding stabilising soft steel angle bars at 45^0 angle at six corners of the frame.

The frame was constructed to support a horizontal axis with a pulley secured midway along the shaft. A cable fixed to a head weight training harness passed through the pulley at head height, so that the line of action was horizontal. The end of the cable was fixed to an adjustable mass. A foam pad was fixed at the end of a metal post secured to the frame and adjustable to the participant's lower sternal area. It was assumed that no significant contraction of the body thoracic or lumbar muscle chain below the level of the support was required (Schieppati et al, 2003). A marker was attached to the pulley which permitted the experimenter to observe if the pulley remained co-planar with a reference point fixed to the supporting structure.

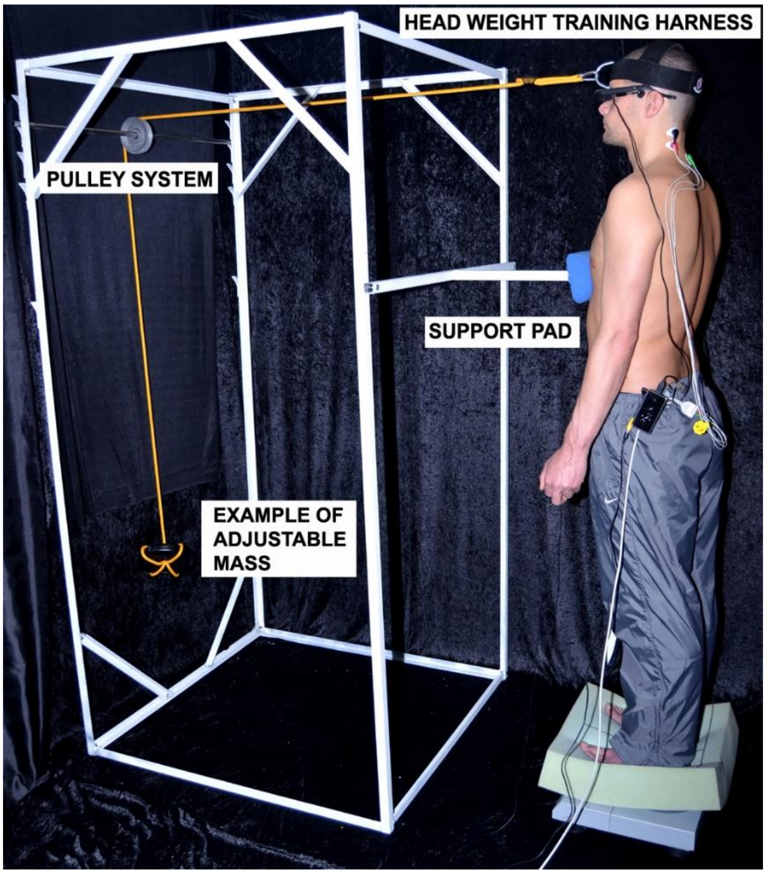


Figure 26 Neck muscle contraction frame and pulley system.

Once the equipment had been fully tested and validated, and the properties of the foams established, it was used to pursue the research described previously. The first experiment measured the effects of different foam properties on balance using the foam samples and the force platform described above.

Chapter 4 - The effects of foam surfaces properties on balance[1]

4.1 Summary

Foam pads are increasingly used on force platforms during balance assessments in order to produce increased instability thereby permitting the measurement of enhanced posturographic parameters. A variety of foam pads providing different material properties have thus been used, although it is still unclear which characteristics produce the most effective and reliable tests. Furthermore, the effects of participant bodyweight on the performance of the foam pads and outcome of the test are unknown. This part of the research investigated how different foam samples affected postural sway velocity in participants of different weights.

Firstly, four foam types were tested according to a modified American Society for Testing and Materials (ASTM) standard for testing flexible cellular materials and their effective Young's modulus calculated.

Thirty-six healthy male factory workers divided into three groups according to body mass were then tested three times for each of 13 randomly-selected experimental situations and changes in postural sway velocity recorded. Descriptive and inferential statistics were used to compare the results and evaluate the difference in sway velocity between mass groups.

4.2 Introduction

Posturography has been shown to be useful in the workplace, for example to assess different-aged workers in physically demanding jobs (Punakallio, 2003),

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[1] The key findings of this chapter have been submitted for publication:
G Gosselin, MJ Fagan. Foam pads properties and their effects on posturography in participants of different weight. Submitted to *Chiropractic & Manual Therapies*.

to measure sleepiness and fatigue (Forsman et al., 2010), and even to observe the effects of neurotoxicity due to workers exposure to organic solvent mixtures (Zamyslowska-Szmytke and Sliwinska-Kowalska, 2013). Furthermore, there is now a trend in Western countries to increase the age of retirement (Munnell, 2011). This aging workforce may in some instances be placed at risk should their functional capacities such as balance become altered. Approximately one person in three over the age of 65 has at least one fall a year and one person in five who falls after the age of 65 for reasons connected with balance dies in the year following the fall (St-Pierre, 2007). In addition obese adults fall nearly twice as often as their non-obese counterparts.

Thus, this chapter's main purpose was to determine how a range of foam pads (including bi-layer foam pad) combinations influenced postural sway velocity during quiet stance for subjects of different body mass.

4.3 Method

Thirty-six healthy male factory workers (mean age = 39.7±9.3years; mass = 88.4±14.1kg; height = 1.78±.034m; BMI = 28±3.1) volunteered to participate in this cross-over study. All participants were physically active and none had neurological, vestibular, visual or musculoskeletal complaints at the time of the experimentation. The participants were divided into three groups according to mass (Group 1: less than 60kg, n=5; Group 2: 60.1kg to 89.9kg, n=23; Group 3: greater than 90kg, n=8). Ethical approval was obtained for the posturography assessment from the University's Ethics committee and the procedures followed were in accordance with the ethical standards of the Helsinki Declaration of 1975, as revised in 2013 (World Medical, 2013). All participants read the information sheet and signed the consent form.

Postural sway velocity was recorded with the use of a force platform (QPS-200, Midot Medical Technology) linked via a USB connector to a laptop computer and the signal processed with Posture Analyser software (Midot Medical

Technology). Postural sway velocities provided by the Posture Analyser software were saved in separate files on a computer.

4.4 Procedure

Posturography was measured three times for each of 13 randomly-selected experimental situations (no foam, four samples of mono-layered foam, and eight samples of bi-layered foam). The order of each test was determined by a random sequence generator (http://www.random.org/sequences/). The bi-layered form consisted of the foam pad covered by either a square $0.25m^2$ or $0.09\ m^2$, 2cm wooden board. The values of the three posturographic records were averaged and used for analysis.

Participants were instructed to stand on the force platform with their feet together and eyes closed. Recording was started after 30 seconds of quiet stance. After recording was complete, participants were allowed to step off the platform and relax for one minute before the procedure was repeated two additional times. Once the three recordings were completed, the participants were asked to stand off the force platform and the experimenter changed the foam sample according to the pre-determined sequence. Posturography was again recorded. Sampling was recorded for 30 seconds (Prosperini et al., 2013) at 33Hz per channel.

4.5 Analysis

The overall posturographic data and the participants' posturographic data grouped by mass were both tested for normality using the Shapiro-Wilk test. Descriptive statistics presented the mean sway velocity ($\bar{x}$), interquartile range, 95% confidence interval for $\bar{x}$ and sway velocity per mass category. Statistical tests were used to determine change in postural sway velocity. One-way repeated measures analyses of variance (ANOVA) with Greenhouse-Geisser corrections were used to compare postural sway velocity in the 13 experimental situations between 1) balance without foam surfaces and 2) balance with 12 other foam combinations. Wilcoxon-signed rank tests were used to evaluate the difference in sway velocity between mass groups. Levels of significance were set at 0.05 and the Bonferroni post-hoc test was used in the ANOVA and Wilcoxon-signed rank tests. Statistical analyses were performed using SPSS Statistics 17.0.

4.6 Results

The Shapiro-Wilk normality tests for changes in postural sway velocity in all participants suggested that normality was a reasonable assumption (p>.05). On the other hand, when participants' results were stratified by body mass, the velocity data was not normally distributed (p<.05).

A repeated measures ANOVA with a Greenhouse-Geisser correction determined that postural sway velocity differed significantly between surfaces measured (F(1.984, 22.257) = 21926.764, P < 0.0001). Post hoc tests using the Bonferroni correction revealed that postural sway velocity was significantly increased especially when standing on a monolayer upholstery foam and on a monolayer balance pad (75.6±0.18.7 mm/s and 78.7±13.5 mm/s respectively).

Wilcoxon signed-rank tests with Bonferroni corrections showed that in three experimental situations, the postural sway velocities were significantly different in participants of different masses (<60kg vs 60-89kg, upholstery foam, Z=-6.156, p=.009; 60kg vs >90kg, upholstery foam, Z=-1.950, p=.012; <60kg vs 60-89kg, upholstery foam and large board, Z=-2.646, p=.010; 60-89kg vs >90kg, upholstery foam and large board, Z=-2.521, p=.012) (Table 14, 15).

Table 14 Mean, coefficient of variation, interquartile range and confidence intervals for overall posturographic results and participants' results stratified by body mass

	$\bar{x}$ (SD) mm/s	CV	IQR	95% CI for $\bar{x}$		<60kg		60-89kg		>90 kg	
						$\bar{x}$	Mdn	$\bar{x}$	Mdn	$\bar{x}$	Mdn
No foam	25.1 (5.2)	0.21	18.7	21.1	27.7	29.1	21	24.0	28.5	24	28.5
MF-75mm	23.4 (6.1)	0.26	15.5	19.7	22.6	27.1	18	22.3	27.1	21	25.5
MF-100mm	22.3 (4.9)	0.22	14.7	18.4	21.4	26.1	17	21.2	25.8	20	24.5
Uph-100mm	75.6 (7.4)	0.10	23.2	69.2	85.7	81.9	82	82.1	49.5	45	49.5
BP-50mm	78.7 (7.1)	0.09	23.7	74.1	82.7	83.2	79	82.0	66.5	62	66.5
MFL-75mm	27.0 (4.6)	0.17	18.3	23.1	27.7	30.9	24	26.1	28.8	24.3	28.8
MFL-100mm	32.8 (6.9)	0.21	18.7	28.8	29.7	36.8	36	31.4	30.5	26	30.5
UphL-100mm	64.5 (6.3)	0.10	24.5	59.3	67.7	69.7	64	57.0	81.4	76	81.4
BPL-50mm	33.0 (2.5)	0.08	19.75	29.2	33.7	36.9	30	33.0	32.5	28	32.5
MFS-75mm	25.5 (6.6)	0,25	19.1	21.4	26.8	29.6	21.4	24.4	28.7	24.1	28.6
MFS-100mm	29.0 (5.3)	0.18	18.5	24.5	42.7	33.4	39	24.6	28.6	23.5	28.0
UphS-100mm	48.4 (3.7)	0.07	20.5	43.6	44.7	53.3	41	44.0	63.5	59	63.5
BPS-50mm	34.0 (3.1)	0.09	19.8	30.0	34.7	38.1	31	34.0	33.5	29	33.5

$\bar{x}$ (SD) = average velocity and its standard deviation. IQR = Interquartile range. CI = 95% confidence interval for the average velocity of sway.
MF: memory foam; Uph: upholstery foam; BP: balance pad; large bi-layer with a surface of 0. 25m board: MFL: memory foam large; UphL: upholstery foam large; BPL: balance pad large; small bi-layer with a surface of 0.09m : MFS: memory foam small; UphS: upholstery foam small; BPS: balance pad small. (n = 36)

4.7 Summary

The balance pad produced the largest postural sway velocity in participants with less than 90 kg mass whilst the bi-layer upholstery sample (large board) produced the largest changes in participants above 90 kg of mass. The results suggest that foam pads selected for static computerised posturography: 1) could possess a modulus of elasticity of around 40kg/m^3, and 2) show linear deformation properties matched to the participants' mass.

The information gathered in this experiment is used to select the appropriate pad during balance testing presented in Chapter 5.

Table 15 ANOVA Pairwise comparison between velocity of sway without foam and with different foam surface **(n = 36)**

		p	95% CI for Difference with No Foam	
Mono-layer	MF-75mm	ns	-0.3	3.7
	MF-100mm	.002	0.6	5.0
	Uph-100mm	.001	-61.0	-39.9
	BP-50mm	.001	-58.8	-48.2
Bi-layer 0.09m²	MFL-75mm	.030	-3.6	-0.08
	MFL-100mm	ns	-15.1	-0.2
	UphL-100mm	.001	-44.5	-34.1
	BPL-50Lmm	.001	-9.2	-6.5
Bi-layer 0.25m²	MFS-75mm	ns	-2.2	0.8
	MFS-100mm	ns	-8.4	0.6
	UphS-100mm	.001	-27.2	-19.3
	BPS-50mm	.001	-10.2	-7.5

Chapter 5 built on the results of the present experiment by using the bi-layered upholstery foam pad during posturography. Participants were submitted to a neck muscle fatigue protocol and balance along with the involved neck muscles electric activity was recorded.

Chapter 5 - Effects of cervical muscle fatigue on muscle groups EMG activity and on balance[2]

5.1 Introduction

Neck muscle fatigue has been shown to alter an individual's balance in a similar way to that reported in subjects suffering from neck pain or subjects that have suffered a neck injury. The main purpose of the present study was to quantify the effects of neck fatigue on neck muscle electromyography (EMG) activity, balance, perceived fatigue and perceived stability.

Thus this chapter presents the measurement of the effect of sustained isometric cervical muscle contraction in eight different directions on balance and perceived stability in addition to the measurement of subjects' perception of fatigue and subjects' perception of change in balance. The muscle fatigue protocol involved the use of an adjustable mass held in a static position by the neck muscles over a certain period of time.

5.3 Method

Forty-four (n=44) healthy male players from the National Conference Rugby League premiership (age= 24±2 years; weight= 91±5.5kg, height=1.84±3.2m) volunteered for inclusion in this cross-over design study (Table 20). Exclusion criteria applied included cervical trauma, neck or lower limb pain and visual disturbances during the last three months. Ethical approval was obtained from University's Ethics Committee, and all participants read the information sheet and signed a consent form. Participants were randomized into two equal groups of 22 individuals according to their surnames.

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[2] The key findings of this chapter have been published in:

G Gosselin, MJ Fagan. 2014. The effects of cervical muscle fatigue on balance – a study with elite amateur rugby league players. *Journal of Sports Science & Medicine* 13:2 329-337.

Cervical isometric contraction

Neck muscle fatigue was induced through isometric contractions (Schieppati et al., 2003, Gosselin et al., 2004). Participants were asked to stand comfortably on a predetermined target, with feet touching each other on a force platform covered by a bi-layer foam pad with their arms to their side and leaning slightly towards a support pad. This was provided to help stabilize body movement during the experiment, and was part of a custom built supporting structure (Figure 27).

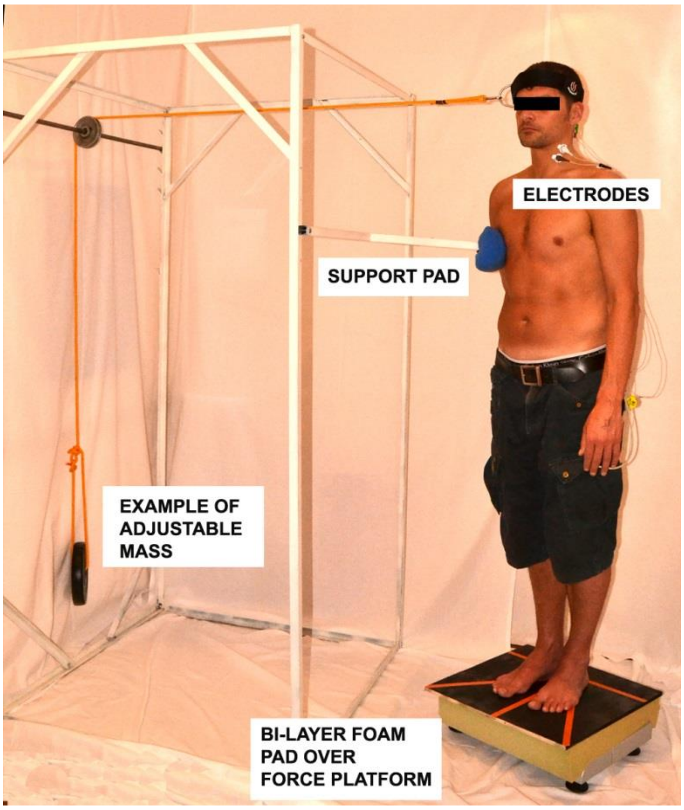

Figure27 Experimental setup showing the subject performing an isometric contraction resisting the adjustable mass in the left posterior oblique direction (LPO)

A head weight training harness was placed on the participant's head, from which a cable extended horizontally (standardized between participants) and was attached via a pulley system to an adjustable mass. Surface EMG electrodes were placed on his shoulder and neck. No significant contraction of the thoracic or lumbar muscle chain below the level of the support was assumed necessary in order to maintain a steady stance. A marker was attached to the pulley and the experimenter observed if the pulley remained co-planar with a reference point fixed to the supporting structure. During the isometric contraction, the experimenter would give a verbal cue in order for the participant to either increase or decrease the cervical muscle force against the weight thereby maintaining a static head/neck position during 15 minutes. This was sufficient to ensure negligible head movement during neck muscle contraction. Eight different effort orientations were used each at 45° offset from the previous one (Figure 28). In order to decrease bias due to a participant's tiredness, the experiment was conducted over two days. On day one, group 1 was tested in four randomized orthogonal positions (*viz.* E, F, RLF & LLF). On day two the remaining effort orientations were tested (*viz.* RPO, LPO, LAO & RAO). The order was reversed for Group 2.

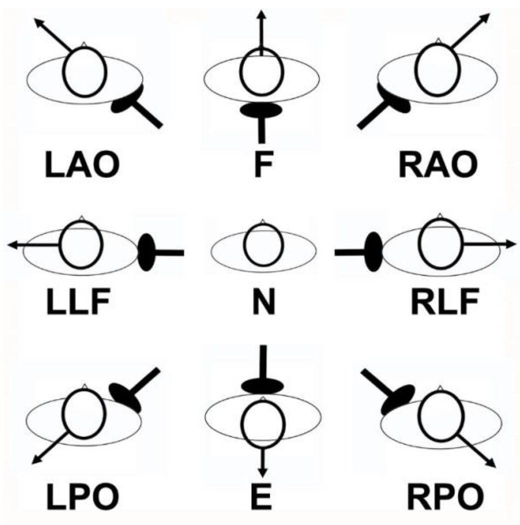

Figure 28 The orientation of efforts and position

Neutral (N), extension (E), right posterior oblique (RPO), right lateral flexion (RLF), right anterior oblique (RAO), left posterior oblique (LPO), left lateral flexion (LLF), left anterior oblique (LAO) and flexion (F).

The load set on the cable was approximated to 35% of the maximum isometric voluntary contraction (Table 16), and was calculated individually for each participant by adapting the isokinetic neck strength profile of elite rugby players data (Olivier and Du Toit, 2008). Olivier's isokinetic values were less than other reported values, but nonetheless allowed to standardise the loads used (Geary et al., 2013). Additionally, the peak torque results were slightly different for the left and right side (3%). We therefore averaged the left and right peak torque in order to obtain a symmetrical resistance for each side. The mass in kilograms used in each subject for a particular movement was obtained by dividing the peak torque presented in the database by the subject's neck length. This peak force was divided once more by the gravitational constant ($9.8m/s^2$) to obtain the mass used in kilograms. Neck length was measured from the spinous process of the vertebral prominence (C7) to the occipital notch at the base of the skull, while the head was held in the Frankfort plane (Olivier and Du Toit, 2008).

Due to the absence of normative data for the oblique contractions, we averaged the torque from either the extension and lateral flexion or the lateral flexion and flexion. For example, the RPO load was determined by averaging the E and RLF torques.

Table 16 Example of the average masses in kilograms used in each subject for a particular movement

Direction	E	RPO	RLF	RAO	LPO	LLF	LAO	F
Average torque (Nm)[1]	56.2	59.5	59.7	50.5	59.5	58.9	50.5	38.9
Peak mass (kg)	54	57.2	57.4	48.6	57.2	56.6	48.6	37.4
35% Peak mass (kg)	18.9	20.0	20.1	17.0	20.0	19.8	17.0	13.0

The mass was obtained by dividing peak torque adapted by from Oliver and Du Toit (2008) by each subject's neck length. The mean neck length was 10.6cm (n = 44). This peak force was divided once more by the gravitational constant to obtain the load used in kilograms. (Adapted from Olivier and Du Toit, 2008)

5.3.1 Electromyography

Surface electromyography was used to assess changes in the muscles involved in isometric contraction, with a two-channel EMG system used to record the SEMG signal during the isometric contraction (iWorks system Model 214, Dover, USA). Standard settings were selected for the assessment, with the low pass filter set to 500Hz, the high pass filter to 10Hz, and the gain to 500 with the common mode rejection ratio set to 110dB. The subjects were standing in a relaxed position with the arms on each side of the body. The anatomical landmarks were detected by palpation. The skin was shaved and rubbed with abrasive paper and the skin was cleaned with 70% alcohol. The inter-electrodes distance (Ag/AgCl) was 2 cm. Due to the difficulty in accessing specific muscles with surface electrodes, the electrode placement was location-specific rather than muscle-specific (Strimpakos et al., 2005). Electrode placements for the different directions of contraction are presented in Table 17.

Table 17 Surface EMG electrode placement and potential contribution of each muscle to different actions produced

Muscle group	Electrode placements	Action associated with muscles	Reference electrode
Splenius capitis (SC)	Over the muscle belly at C2/3 level between the uppermost parts of trapezius and sternocleidomastoid	RPO, RLF, RAO, LPO, LLF, LAO	C7 spinous process
Sternocleidomastoid (SCM)	Over the muscle belly, about 1/3 of the length rostral to the sternal attachment	RLF, RAO, LLF, LAO, F	Acromion
Cervical paraspinal group (CPG); trapezius, capitis and cervicis groups)	2 cm from the midline at C4 level	E, RPO, LPO,	T1 spinous process

Figure 29 and 30 show the involved muscles. Figure 31 demonstrates electrode placements. Based on the method of Strimpakos et al., 2005

The leads were linked to the skin and connected to the iWorx unit. Sampling started 15 seconds after the onset of the muscle contraction and lasted for 4.096 seconds at a rate of 2 KHz and once more after 14 minutes of isometric contraction. The real time wave form was displayed through LabScribe V2.0 software (iWorx, Dover, USA). The raw EMG was processed by performing a linear magnitude fast Fourier transform (FFT) followed by an integration and normalization of the spectrum (values from 0 to 1 volt), with normalisation achieved through division by the maximum recorded value. The median frequency of the EMG spectrum was then identified at a value of 0.5. Where SEMG was recorded from two muscles, the median frequencies were averaged to produce one single result.

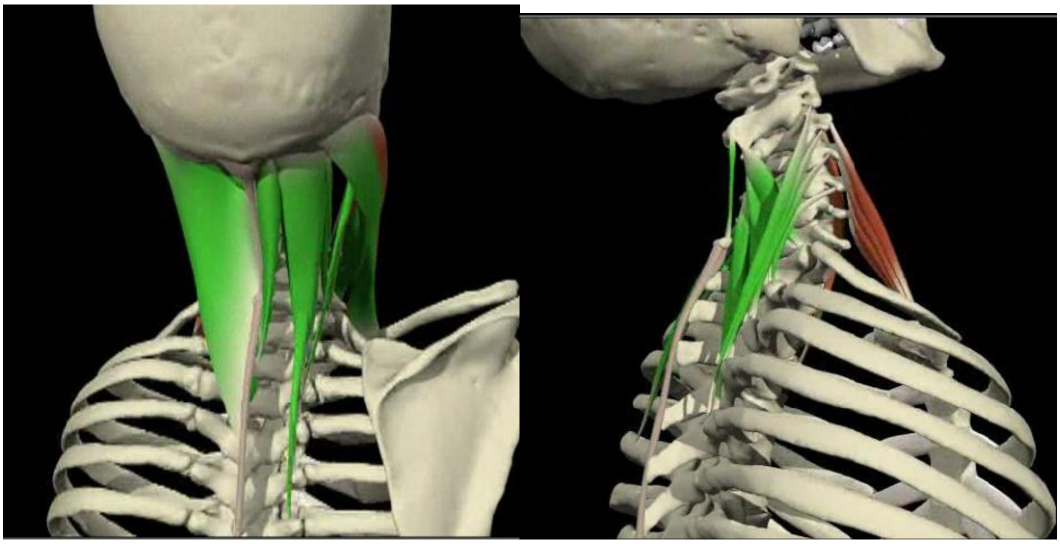

Figure 29 Muscles involved in extension (Adapted from Primal Pictures Ltd, 2011)

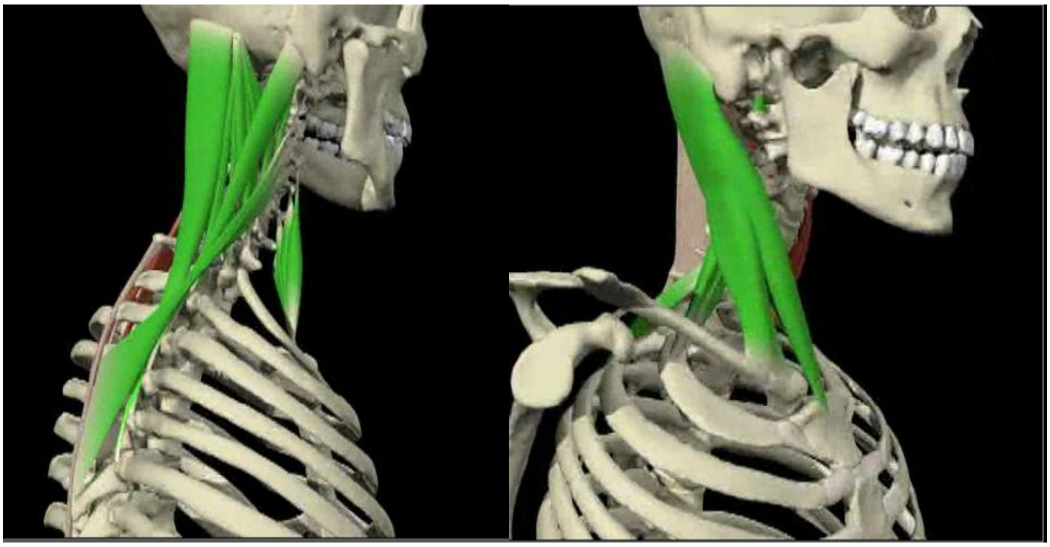

Figure 30 Muscles involved in lateral flexion and flexion (Adapted from Primal Pictures Ltd, 2011)

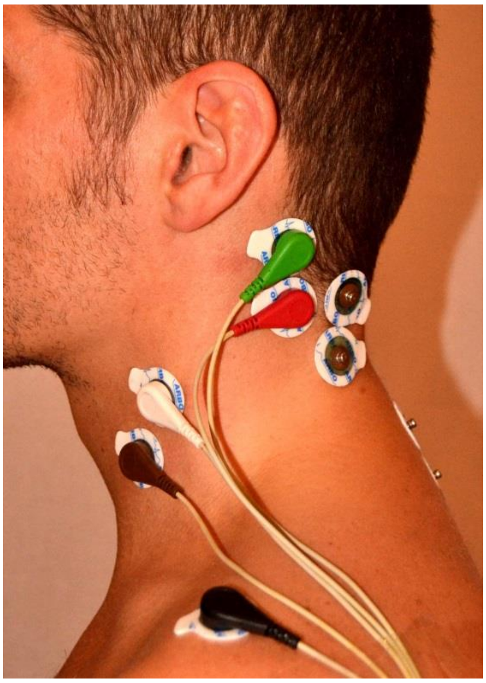

Figure 31 Example of surface EMG electrodes placement on participating model (for illustration purpose only)

5.3.2 Posturography

Postural sway velocity and centre of pressure displacement (COP) were recorded with the use of a force platform (QPS-200, Midot Med. Technology) linked via a USB connector to a laptop computer and the signal processed with Posture Analyser software (Posture Midot Medical Technology). Postural sway velocity and COP displacement plots provided by the Posture Analyser software were saved in separate files on a computer. One 10cm x 50cm x 50cm bi-layer foam pad was placed on the force platform, where the compressive modulus of elasticity of the foam was measured to be 44.9kPa (Gosselin, 2011). Participants were asked to stand on the foam pad, feet touching each other with their eyes closed and without their body touching the apparatus' padded vertical support. Sampling was recorded for 30 seconds (Prosperini et al., 2013) at 33Hz per channel on two occasions: 1) one minute before the isometric contraction was started; 2) 15 seconds after the end of the isometric contraction.

5.3.3 Subjective exertion perception

Participants were asked to rate their perceived fatigue/exertion using the Rating of Perceived Exertion (RPE) Borg CR-10 scale (Table 18). The Borg CR-10 scale consists of a vertical scale labelled 0 to 10 with corresponding verbal expressions of progressively increasing sensation intensity (Borg, 1990).

Table 18 The CR-10 scale

The category (C) scale with ratio (R) properties (Borg, 1990).

0	Nothing at all	
0.5	Extremely weak	(just noticeable)
1	Very weak	
2	Weak	(light)
3	Moderate	
4		
5	Strong	(heavy)
6		
7	Very strong	
8		
9		
10	Extremely strong	(almost max)
	Maximal	

5.3.4 Subjective postural stability perception

Participants were asked to rate their perceived postural stability by using the same stability scale as used by Schieppati (Schieppati et al., 2003). Scores ranged from 10 (I feel really still, as if supporting myself using a stable frame) to 0 (unable to stand without falling) (Schieppati et al., 1999, Schieppati et al., 2003). Shieppati suggested that in normal subjects, a medium score of five would correspond to the sensation of standing upright with one foot in front of the other along the same line (the tandem Romberg position). Standing on one leg with the eyes closed without support, and eventually having to place the other foot on the ground could score zero (Schieppati et al., 1999).

5.3.5 Procedure

The EMG electrodes were applied. The participants stood in a relaxed position with their eyes closed on the foam pad with their body approximately 2 cm away from the support apparatus' padded horizontal support. Posturography was measured for 60 seconds. The head weight training strap was adjusted to the head and the appropriate weight was placed at the end of the cable. During the neck extension muscle sequence, the participants were instructed to lean forward sufficiently for their chest to touch the padded horizontal support and thus maintain the position of the head and neck, and to readjust the position should the experimenter give them a verbal cue. SEMG signals were recorded both from the onset of the contraction and again during the last minute of contraction. These instructions were repeated for to the seven other positions. During the neck extension muscles sequence, the participants were instructed to lean forward sufficiently for their chest to touch the padded horizontal support and thus maintain the position of the head and neck and to readjust the position should the experimenter give them a verbal cue. During the first minute of contraction, participants were shown a Borg CR-10 chart and were asked to select a number on the chart that corresponded to their perceived effort. They were allowed to use any number on the scale and even half values like 1.5 or decimals like 0.8, 1.7 or 2.3 (Dedering et al., 1999). The contraction was maintained for 15 minutes (Gosselin et al., 2004), during the 14^{th} minute, participants were again shown the Borg CR-10 chart and asked to rate their perceived fatigue.

Once 15 minutes of isometric contraction were completed, the head weight training straps were immediately removed and the participant was asked to hold a comfortable standing position with their eyes closed without touching the support pad. The distance away from the support pad was not standardised. Posturography was again measured for 60 seconds. Participants were then asked to rate their subjective feelings of stability. Participants were allowed 15 minutes recuperation between experimental situations. Overall, the experimentation of all four situations lasted between 2.25 to 2.50 hours.

5.4 Analysis

Statistical analyses were performed using SPSS 17.0. The data was tested for normality using the Shapiro-Wilk test. Paired t-tests measured the differences in myoelectic activity and sway velocity between the beginning and end of the isometric contraction. One-way repeated measures analysis of variance (ANOVA) with Greenhouse-Geisser corrections were used to compare myoelectric activity differences and postural sway velocity differences in all eight situations. Paired t-tests compared differences in sway velocity changes after 15 minutes of isometric contraction, RPE (Borg CR-10) and Scheppati scores for each situation individually. Levels of significance were set at .05. Bonferroni correction post-hoc test was performed for all t-tests and ANOVAs. All statistical analysis was performed with SPSS Statistics 17.0.

5.5 Results

The Shapiro-Wilk normality tests for EMG frequency and sway velocity suggested that normality was a reasonable assumption.

5.5.1 Surface Electromyography

Paired t-tests with Bonferroni correction showed that the SEMG median frequency of the cervical muscles recorded during the 1st and 15th minutes of isometric contraction were significantly different in all eight situations (Table 19).

Table 19 Paired sample tests of SEMG median frequency of the cervical muscles recorded

Showing mean and their standard error mean, lower and upper 95% confidence interval of the difference, t statistic (degree of freedom: 43) and significance (n = 44).

Direction	Mean (Hz)	SE means (Hz)	t	95 %CI	p
E	35.5	.43	43	34.6 – 36.4	.001
RPO	33.3	.39	84.5	32.6 – 34.1	.001
RLF	60.7	.55	111.3	59.6 – 61.8	.001
RAO	60.1	.49	122.8	59.1 – 61.1	.001
LPO	32.8	.32	103.6	32.1 – 33.4	.001
LLF	28.1	.25	112.9	27.6 – 28.6	.001
LAO	27.7	.19	142.4	27.3 – 28.1	.001
F	27.6	.17	159.2	26.9 – 27.6	.001

Bonferroni correction for eight situations set significance at less than .0018.

Figure 32 shows changes in median frequency between the first and the last minute of contraction, with the trend line showing that smaller changes were recorded from the anteriorly contracting muscles. A one-way repeated measures ANOVA with Greenhouse-Geisser corrections confirmed that different directions of the 15 minute isometric contractions produced significant changes in the 'before' and 'after' differences SEMG median frequency ($F(4.196, 180.436) = 136.377$, partial $\eta^2 = 0.760$, $p<.001$). Post hoc tests using the Bonferoni correction revealed that changes in SEMG frequency during E were significantly different to all other contractions ($p<.001$). There were no significant changes in before and after differences in median frequencies between the RPO, RLF and LLF. Nor were there any differences between F, LAO and RAO.

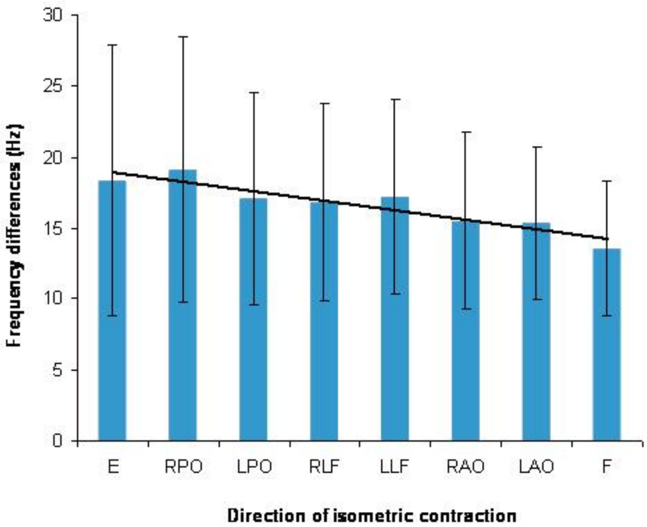

Figure 32 Mean EMG frequency differences (Hz) and standard deviations and linear trend line between initial recording during the first minute of contraction and after 14 minutes in 8 different directions of isometric contraction (n = 44)

5.5.2 Posturography

Descriptive statistics showed the postural sway velocity to be the largest in isometric contractions involving neck extensor muscles. Changes in velocity were the least affected by the isometric contraction during F, LAO and RAO (Figure 33).

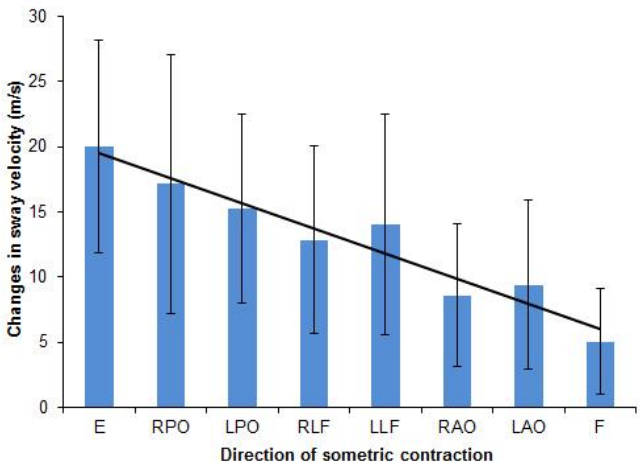

Figure 33 Mean differences in sway velocity and standard deviations and linear trend line after 14 minutes in 8 different directions of isometric contraction (n = 44)

Paired t-tests with Bonferroni correction showed that the postural sway velocity recorded after the 15 minutes isometric contraction produced a significant increase in velocity in E, RPO, and LPO (Table 20).

Table 20 Paired sample tests of postural sway velocity

Showing mean and their standard error mean, lower and upper 95% confidence interval of the difference, t statistic (degree of freedom: 43) and significance (n = 44).					
Direction	Mean (mm/s)	SE mean (mm/s)	t	95 %CI	p
E	10.2	1.6	6.3	6.9 – 13.5	.001
RPO	7.4	1.9	3.9	3.5 – 11.1	.001
RLF	3.1	1.6	1.9	.1 – 6.2	.058
RAO	-1.2	1.4	.842	-4.0 – 1.65	.404
LPO	5.5	1.5	3.6	2.4 – 8.5	.001
LLF	4.3	1.8	2.4	.7 – 7.8	.061
LAO	-.39	1.4	.268	-3.3 – 2.5	.790
F	-4.7	1.0	-4.6	-6.8 - -2.7	.001

Bonferroni correction for eight situations set significance at less than 0.0018.

A one-way repeated measures ANOVA with Greenhouse-Geisser correction showed that significant differences were present between the different effort orientations for postural sway velocity changes ($F(5.77, 248.103) = 25.599$, partial $\eta 2 = .373$, $p<.001$). Post hoc tests using the Bonferroni correction revealed that postural sway velocity changes were present predominantly in the sagittal plane of contraction. Mirror contractions in the transverse plane did not show significant differences in sway velocity. LPO vs. RPO, LLF vs. RLF, and LAO vs. RAO were all insignificant, whilst all other interactions were significantly different ($p<.01$).

5.5.3 Centre of Pressure (COP)

After 15 minutes of muscle contraction, all the participants showed oriented whole-body leaning in the plane of the contraction, which lasted so long that the participant had to compensate repeatedly for this disequilibrium. Figure 26 shows observed COP in neutral position compared to the observed COP motor post-effects that are oriented in the same plane of contraction. Nevertheless, the spatial characteristics of the postural post-effects varied according to the cervical muscle group previously contracted. While postural post-effects were oriented in one direction, the positive or negative value differed in each participant. For example, all participants increased COP displacement in the sagittal plane after contraction, but as seen in previous studies, half of the participants moved forward and half moved backwards. This was observed again in this study, but to a lesser extent during lateral and anterior oblique contractions (Figure 34).

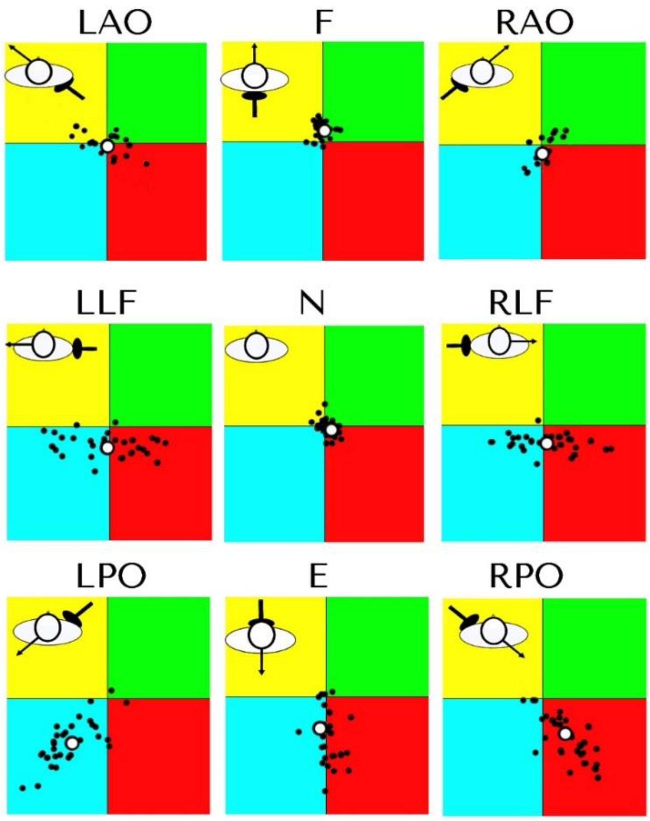

Figure 34 Centre of pressure (COP)

Centre of pressure (COP) motor post-effects (leaning) are seen oriented in the same direction of contraction after 15 minutes isometric contraction. Extension (E), right posterior oblique (RPO), right lateral flexion (RLF), right anterior oblique (RAO), left posterior oblique (LPO), left lateral flexion (LLF), left anterior oblique (LAO), and flexion (F). White circle represents average change in COP (n = 44).

5.5.4 Subjective perception of effort and balance

A one-way repeated measures ANOVA with Greenhouse-Geisser corrections showed that participants' perception of stability was changed after 15 minutes neck muscle isometric contractions in different directions ($F(1.155, 49.564) = 274.03$, $p<.001$, partial $\eta^2 = .989$). Post-hoc tests using the Bonferoni correction showed that the participants' perceived decrease in stability after isometric contraction occurred mostly during contractions involving some lateral movement (Figure 32). Perception of effort (RPE), conversely, was not significantly different between directions of contraction (Figure 35).

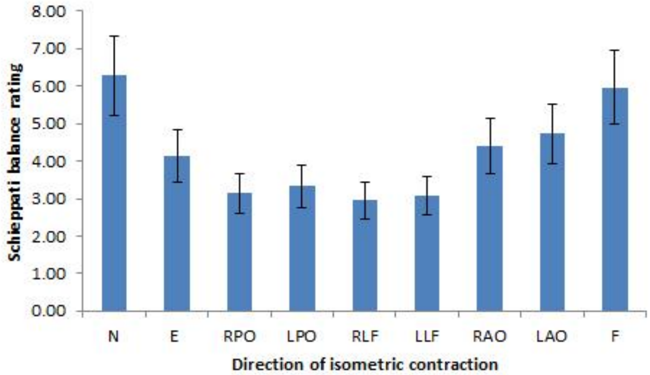

Figure 35 Pre and post-isometric contraction perceived sway (n = 44)

The perceived sway and standard deviation between normal stance feet together/eyes closed (N) and after 15 minutes isometric contractions in eight different positions. Feeling of decreased stability is represented by a lower score.

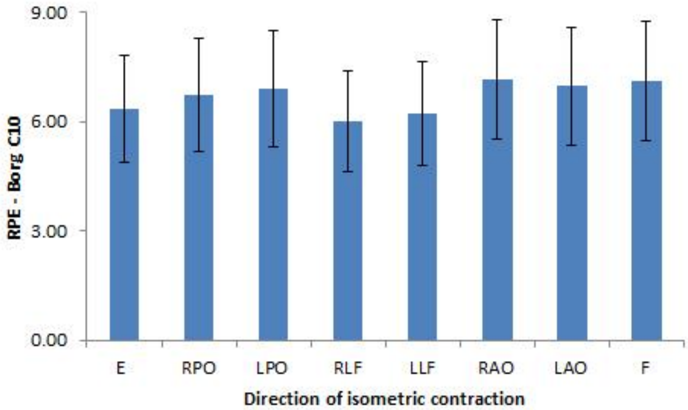

Figure 36 Pre and post-isometric contraction perceived exertion (n = 44)

Figure 36 shows the perceived exertion and standard deviation after 15 minutes isometric contractions in eight difference positions. A feeling of more intense effort is represented by a higher score.

5.6 Summary

Fifteen minutes of constant neck muscle 35% MVIC in eight different directions in the standing position produced significant altered and perceived altered balance in elite amateur rugby league players. The median frequency EMG and sway velocity were most affected during posteriorly oriented contractions. This was the first study to investigate the effects of eight different directions of neck muscle isometric contraction. The results may contribute eventually to our understanding of normal functional capacities of athletes and may provide a basis for further investigation in healthy non-athletes and participants that have suffered neck injuries.

The following chapter continues the investigation on cervical functional capacities by measuring the effects of cervical muscle fatigue protocol on field dependency with the use of the Rod and Frame Test.

Chapter 6 - Effects of cervical muscle fatigue on the perception of the subjective vertical and horizontal[3]

6.1 Introduction

Cervical functional capacity outcome measures that are simple and reliable are urgently needed in order permit accurate assessment/reassessment during treatments and rehabilitation. Induced neck muscle fatigue has been shown to alter functional capacities such as balance and kinaesthetic sense in the standing posture. The Rod and Frame Test (RFT) has also demonstrated promise as a method of assessing the effects of chronic neck pain and injury, but currently only in the sitting position.

This first goal of this phase of the research was to confirm that a modified C-RFT^{dot} method could be used reliably while participants were standing. The sitting C-RFT^{dot} methodology as developed by Bagust (2005) was modified in order to: 1) decrease the possible proprioceptive cues provided by the sitting position and by both arms touching the computer keyboard and mouse; and 2) reproduce posturographic protocols that are used in many laboratories enabling the experimenters to combine two or more tests in the standing posture. The second goal was to investigate if fatiguing different neck muscle would alter healthy subject's ability to perceive the subjective visual vertical and horizontal.

6.2 Method

Seventy four (n=74) healthy male volunteers (23 ± 2 years old; weight= 89.2±6.2kg, height= 1.82±3.5cm) were recruited from local amateur rugby league and football teams. None were compensated for participating in the

[3] The key findings of this chapter have been published in:

G Gosselin, MJ Fagan. 2014. Effects of cervical muscle fatigue on the perception of the subjective vertical and horizontal. *SpringerPlus* (Biomedical and Life Sciences) 3:78.

study. Inclusion criteria included absence of injuries within the last six months, not wearing spectacles and being fit to play. Ethical approval was obtained from the University's Ethics Committee and all participants signed a consent form after reading an information sheet.

6.2.1 Validation of C-RFT^{dot} standing

Participants were randomised into two equal groups (group A: n = 37 ; group B: n = 37) according to their surname. All subjects took the C-RFT^{dot} both sitting (T_1) and after 15 minutes rest in the standing position (T_2), but there was no time constraint to perform the tests. The order of the tests was determined by a list randomiser (www.random.org). Participants performed the test in a darkened room wearing computerised video goggles (Shenzen EOS Electronics Co, Hong Kong) which effectively simulated the viewing of a 183cm screen from a 2m distance. Eye patches attached to the video goggles were used to help limit peripheral vision. Participants were presented with a white square acting as the frame (Figure 37).

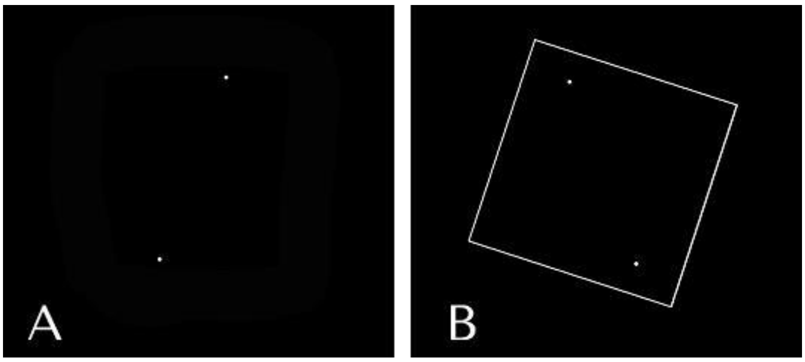

Figure 37 Computer screen capture of test
A Dots. B Dots and tilted frame (at +18°).

Two superimposed dots were shown inside the square. The subjects were instructed to use the right and left computer mouse buttons in order to move the dots around their imaginary centre in clockwise or counter clockwise paths. The dots' movements were made in 0.5° increments up to a maximum of 30° rotation from the vertical in either direction. A pre-programmed session of 18 situations was presented where there was: 1) an absence of the square; 2) the square frame levelled (0°, frame°); 3) square frame angled clockwise +18° ($frame^{+18}$); or 4) square frame angled counter clockwise -18° ($frame^{-18}$). All situations recurred randomly four times as determined by the programme and two additional practice situations completed the test with the dots angled clockwise (+20°) or counter clockwise (-20°) (Docherty and Bagust, 2010). Participants were asked to move the dots as close as possible to their perception of the gravitational vertical. Once they had confirmed the alignment using the space bar, the image would clear and the next sequence would appear.

Figure 38 C-RFT^{dot} positions

A. Participant is sitting at a desk and controls the mouse with the right hand while the left hand validates the trial. **B**. Standing position. The participant controls the dots and validates the trial with one hand. **C**. Close up view of the hand held mouse in the participant's hand.

Participants would take on average between two and four minutes to complete the test. The second set (T_2) of experiments was performed during quiet stance with the arms relaxed to the side of the body. Participants held a hand held mouse to control the dots and validate the test sequence, allowing the arms to remain at the side of the body (Figure 38).

6.2.2 Neck muscle fatigue

Fifty-six (n=56) participants who took part in the validation study volunteered to participate on different days in the neck fatigue experiment. None were compensated for participating in the study. Participants were randomised into two equal groups (group A: n = 28; group B: n = 28) according to their surname. Neck muscle fatigue was induced by the participants undertaking isometric contractions (Schieppati et al., 2003, Gosselin et al., 2004). They were asked to stand naturally, the feet comfortably apart, with their arms to their side and leaning slightly towards a support pad. This was provided to help stabilise body movement during the experiment, and was part of a custom built supporting structure (Figure 39). A head weight training harness was placed on the participant's head, from which a cable extended horizontally and was attached via a pulley system to an appropriate mass. No significant contraction of the body thoracic or lumbar muscle chain below the level of the support was assumed required. A marker was attached to the pulley and the experimenter observed if the pulley remained co-planar with a reference point fixed to the supporting structure. During the isometric contraction, the experimenter would give a verbal cue in order for the participant to either increase or decrease the cervical muscle force against the weight thereby maintaining a static head/neck position.

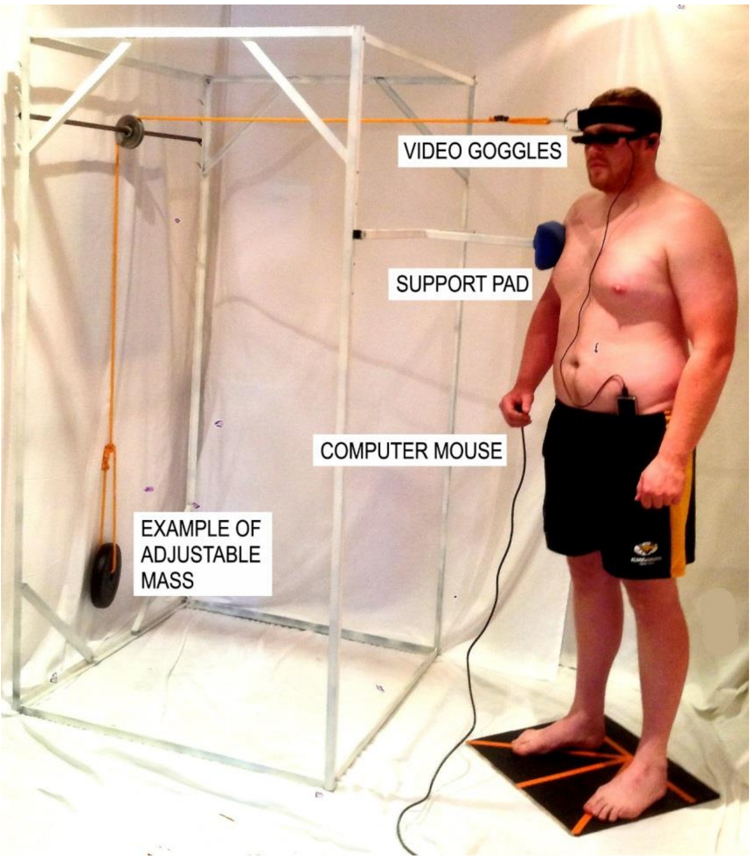

Figure 39 Experimental setup showing the participant performing an isometric contraction

The direction of contraction is in the left posterior oblique direction (LPO). The participant is holding a computer mouse in the right hand. The effort is produced against a cable placed over a pulley to an adjustable mass.

Eight different positions were used each at a 45° offset from the previous one (Figure 40). The orientation of efforts were in extension (E), right posterior oblique (RPO), right lateral flexion (RLF), right anterior oblique (RAO), left posterior oblique (LPO), left lateral flexion (LLF), left anterior oblique (LAO) and flexion (F) (Figure 42). In order to decrease bias due to a participant's overexertion, the experiment was conducted over two days. On day one, Group A was tested in four different directions each at 90^0 from the other: E, F, RLF, LLF; on day 2: RPO, LPO, LAO, RAO. The order was reversed for Group B.

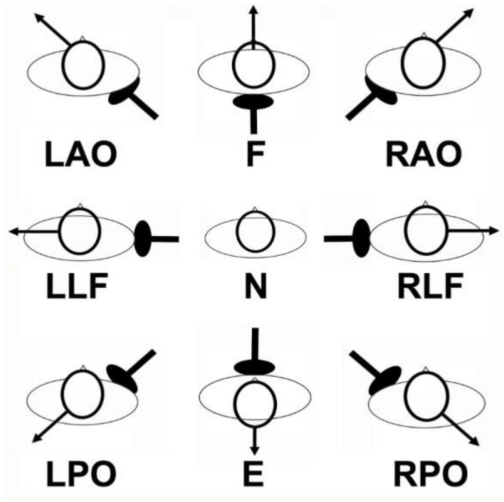

Figure 40 The orientation of efforts and position

The load set on the cable was approximated to 35% of the maximum isometric voluntary contraction as used by Stapley and Schieppati (Stapley et al., 2006, Schieppati et al., 2003) (Table 21). In order to avoid risks of injuries during maximum voluntary contraction measurements, the load was calculated individually for each participant by using the isokinetic neck strength profile of elite rugby players and healthy adults (Olivier and Du Toit, 2008, Hogrel et al., 2007). The mass in kilograms required for each participant for a particular movement was then obtained by dividing the peak torque presented in the database by the participant's neck length and gravitational constant ($9.81 m/s^2$). Neck length was measured from the spinous process of the vertebral prominence (C7) to the occipital notch at the base of the skull, while the head was held in the Frankfort plane (Olivier and Du Toit, 2008).

Table 21 The masses and loads used by the participants for a particular movement (n = 74)

Direction	E	RPO	RLF	RAO	LPO	LLF	LAO	F
Average torque (Nm)	59.4	56.9	54.3	45.7	57.5	55.6	46.4	37.1
Peak mass (kg)	57.2	54.8	52.3	44.0	55.4	53.5	44.7	35.7
35% Peak mass (kg)	20.0	19.2	18.3	15.4	19.4	18.7	15.6	12.5

Due to the absence of normative data for the oblique contractions, the torque from either the extension and lateral flexion or the lateral flexion and flexion were averaged. For example, the RPO load was determined by averaging the E and RLF torques.

6.2.3 Fatigue and C-RFT^{dot} procedure

The participants stood in a relaxed stance in one of the predetermined positions with their body approximately 2 cm away from the padded vertical support of the apparatus. The C-RFT^{dot} test was started. Once the test was completed, the head weight training strap was applied to the head and the appropriate weight placed at the end of the cable. During the neck extension muscle sequence, the participants were instructed to lean against the padded vertical support and thus maintain the position of the head and neck, and to readjust the position should the experimenter give them a verbal cue.

After 15 minutes of isometric contraction, the experimenter immediately removed the head weight training straps from the participant's head and asked the participant to hold a comfortable standing position. Once their position had stabilised, the second C-RFT^{dot} test was started. Participants were allowed 15 minutes recuperation between experimental situations. Overall, the experimentation of the four situations lasted between 2.15 to 2.45 hours.

6.3 Analysis

Each participant's errors in aligning the rod were used to calculate the absolute means or unsigned or signed values for each of the eight test situations. The direction of the error was determined by the average signed results which indicated the direction of errors whilst the magnitude was determined by the absolute errors. All analyses were performed using SPSS 17.0 and GraphPad Prism 6. Data were tested for normality using the Shapiro-Wilk test. The data are given as median ± standard deviation (SD). As our data were not normally distributed, we looked for correlation between sitting and standing C-RFT^{dot}

results with the use of the Spearman's correlation coefficient test. Furthermore, agreement between the two methods was analysed with the Bland-Altman method on signed errors.

Wilcoxon Signed-Rank tests were used to determine if there were differences in the absolute C-RFT^{dot} errors between the neutral positions and all other eight directions of contraction. Wilcoxon signed rank tests therefore analysed changes in horizontal and vertical C-RFT^{dot} errors between the neutral and eight different directions of contraction. The changes of recorded C-RFT^{dot} unsigned (absolute) vertical and horizontal errors for the combined frame condition in all eight situations of isometric contraction were analysed with two respective one-way repeated measures ANOVA with Greenhouse-Geisser correction. The Bonferoni correction was used as post-hoc tests. The use of a parametric test for non-normally distributed data can be justifiable because, even with non-normal distributions at the participant level, with a large enough sample size, such as in our case (n=56), the distributions of the sample means become sufficiently normal for the ANOVA to be robust enough to analyse the data (Lumley et al., 2002). Significance levels were set at .05.

6.4 Results

6.4.1 Validation

The Shapiro-Wilk test shows that the recorded positioning errors are not normally distributed (p<.001), as shown in Figure 41. The results suggest that the relationship between the C-RFT^{dot} absolute errors in the sitting and standing positions is highly significant for the SVV (rho = 0.982, p = .01) and for the SVH (rho = 0.950, p = .01).

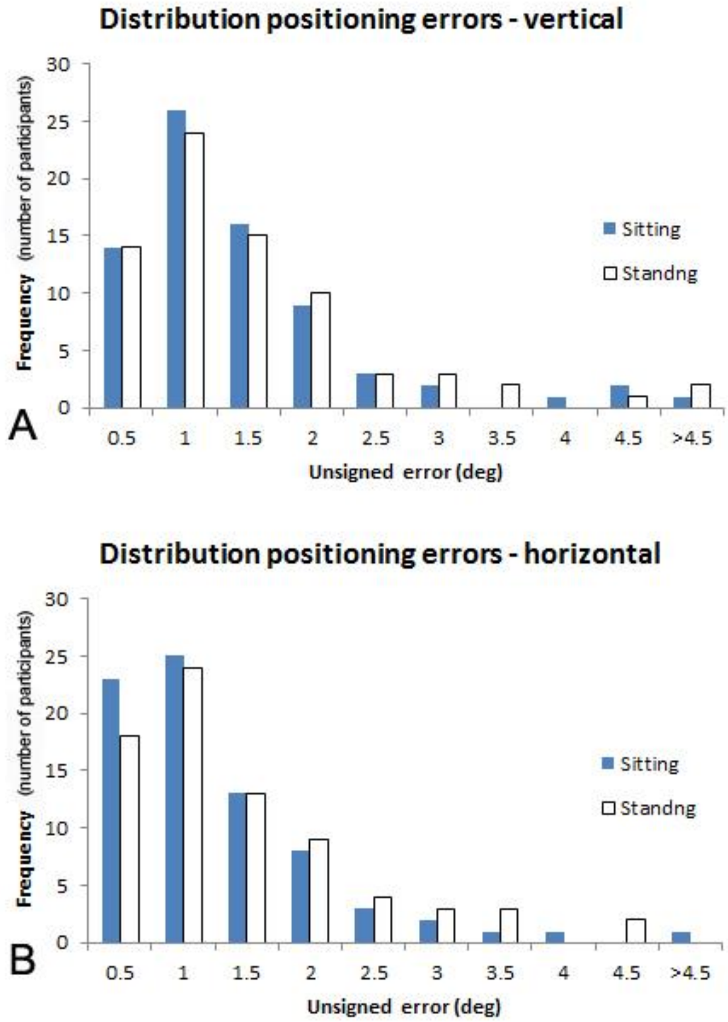

Figure 41 Distribution of the unsigned errors for the combined frame +18 and frame -18 values. (A) Vertical, (B) Horizontal. (n = 74)

The Bland-Altman analysis indicates that the 95% limits of agreement between the two methods ranged from –1.49 to 1.11 vertically and -1.33 and 1.48 horizontally (Figure 42). The two methods consistently provide similar measures.

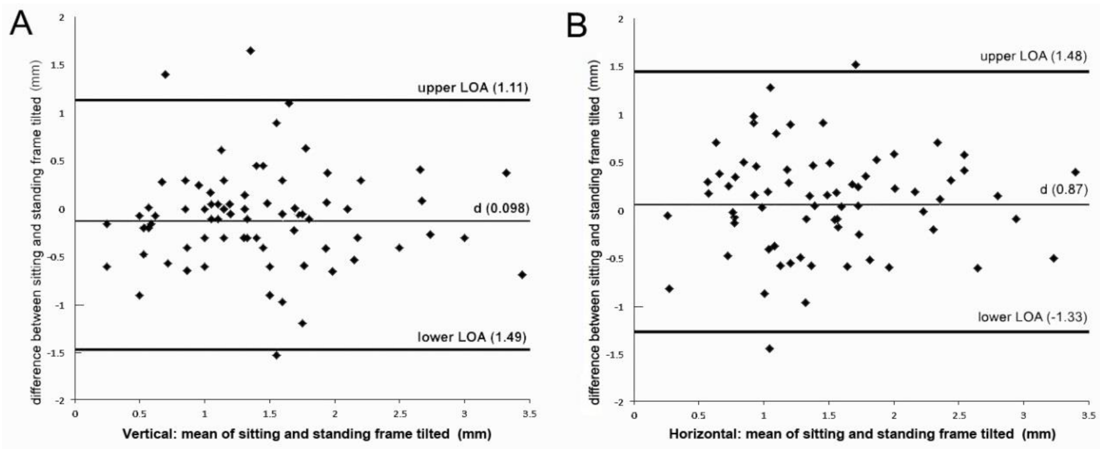

Figure 42 Bland-Altman analysis of agreement between sitting and standing C-RFT^{dot} results. (n = 74)

6.4.2 RFT^{dot} after isometric contraction

Wilcoxon Signed-Rank tests showed there were statistically significant increases in errors in all subjects both for the horizontal and vertical C-RFT^{dot}, except after flexion both in the horizontal and vertical C-RFT^{dot} (Tables 22 and 23).

Table 22 Combined horizontal +18 and -18 scores for each isometric direction

Direction	Mean	SD	Median	CI 96.69%	z	p
E	2.22	1.04	0.4	-0.3-8	-4.026	.001
RPO	3.8	0.85	2.2	1.7-2.42	-6.314	.001
RLF	8.22	4.05	5..67	3.9-8.7	-6.535	.001
RAO	4.35	2.45	2.1	1.4-2.7	-6.313	.001
LPO	3.97	2.42	2.9	1.3-3.9	-6.488	.001
LLF	7.67	3.67	5.3	4.0-5.6	-6.568	.001
LAO	3.78	1.85	1.3	0.8-2.7	-6.163	.001
F	1.71	0.81	0.0	-0.24-0.3	-.341	**.733**

This table shows mean and standard deviation, median, lower and upper 96.69% confidence interval of the difference, and the Wilcoxon paired rank z statistic and significance. (n = 74)

Table 23 Combine vertical +18 and -18 scores for each isometric contraction direction

Direction	Mean	SD	Median	CI 96.69%	z	p
E	2.29	0.97	0.8	0.4-1.2	-2.015	.044
RPO	3.86	1.08	2.2	2.0-2.4	-6.520	.001
RLF	6.82	2.66	5.51	3.8-6.6	-6.567	.001
RAO	4.27	2.85	2.2	1.3-2.7	-6.309	.001
LPO	4.5	1.57	2.82	2.6-3.1	-5.618	.001
LLF	7.01	3.11	4.8	3.6-6.3	-6.567	.001
LAO	3.82	1.39	2.2	2.1-2.41	-5.939	.001
F	1.57	0.75	0.0	-.08-0.1	-.029	**.977**

The table shows mean and standard deviation, median, lower and upper 96.69% confidence interval of the difference, and the Wilcoxon paired rank z statistic and significance. (n = 74)

Vertical and horizontal errors with and without tilted frames are shown in figure 43. When no frame was present, there were significant differences ($p<.01$) in the C-RFT^{dot} after contractions in all directions except after E and F on the horizontal test and E, F, RPO and LPO on the vertical test. The effect of tilting the frame 18° clockwise or counter clockwise caused significant increased positioning errors in all situations ($p<.001$) although there was no difference between the unsigned means of the clockwise and counter clockwise tilted frame for both horizontal and vertical results. More importantly, the direction of contraction did not influence the sign of the positioning errors.

When frames were present the one-way repeated measures ANOVAs with Greenhouse-Geisser corrections determined that different directions of 15 minutes isometric contractions produced significant changes between differences in C-RFT^{dot} (vertical errors: $F(4.176, 233.830) = 55.272$, $p<.001$; horizontal errors: $F(3.839, 215.005) = 50.699$, $p<.001$). Post hoc tests using the Bonferoni correction revealed that changes in C-RFT^{dot} errors were predominantly present in the transverse plane of contraction for both the C-RFT^{dot}. vertical and horizontal (Figure 44).

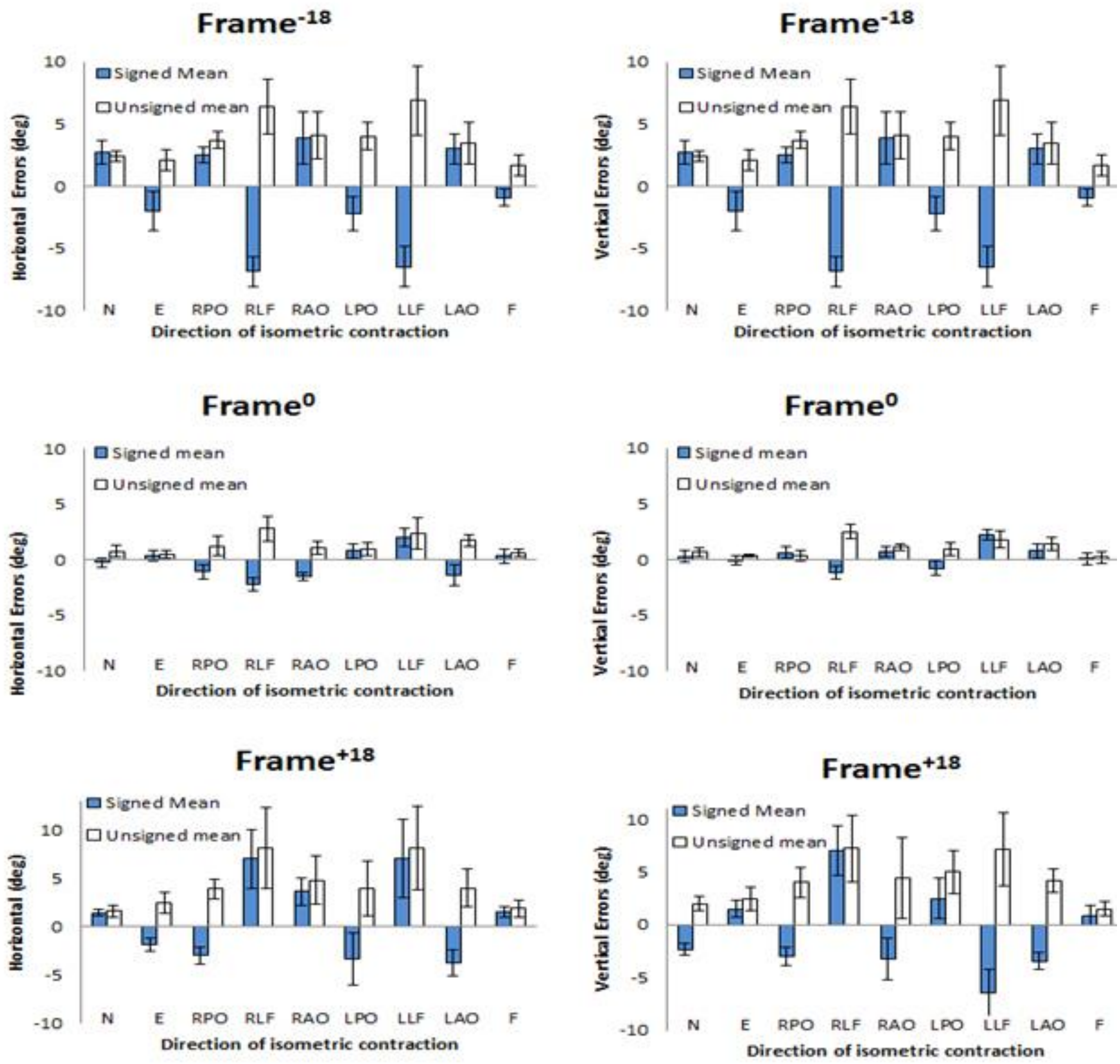

Figure 43 Vertical and horizontal errors with the frame at -18, 0 and +18 (n = 74)

The largest positioning errors are seen after lateral contraction.

There were no significant differences between C-RFT^{dot} horizontal E and F contractions in the sagittal plane ($p>0.6$) nor were there C-RFT^{dot} vertical mean differences between the RPO, RAO, LPO; RLF, LLF; LPO, RPO, LAO. Figure 45 helps to visualise the differences vertical and horizontal combined unsigned errors.

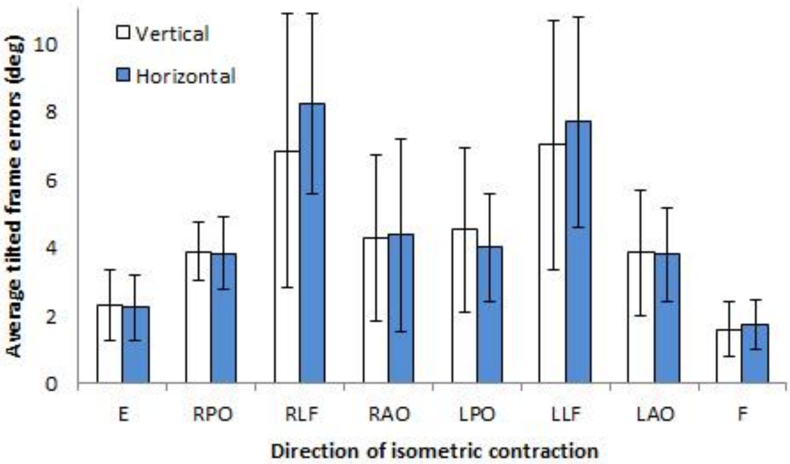

Figure 44 Vertical and horizontal unsigned combined +18 and -18 scores for each isometric contraction direction (n = 74)

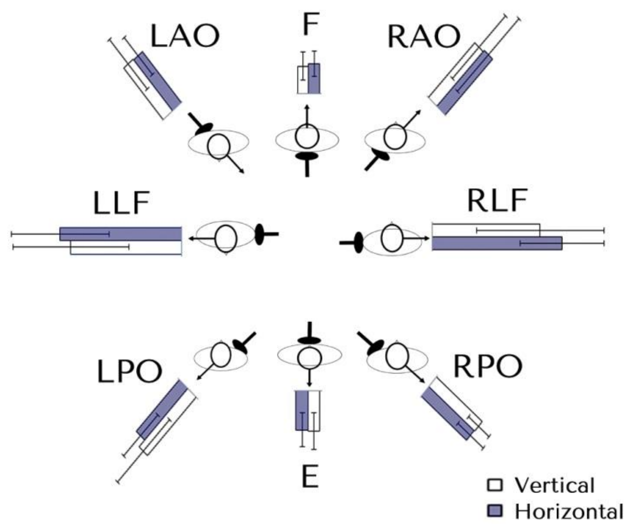

Figure 45 Graphical representation of the vertical and horizontal combine +18 and -18 scores for each isometric contraction direction (n = 74)

6.5 Summary

This experiment has demonstrated that both sitting and standing C-RFT^{dot} methods produce statistically identical results. Furthermore, 15 minutes of constant neck muscle contraction at 35% MVIC in eight different directions in the standing posture increased significantly the C-RFT^{dot} positioning errors in all directions except in the sagittal plane. Proprioception alone cannot explain this phenomenon and it is suggested that an evolutionary advantage of developing improved subjective verticality awareness in the same direction as the main visual field could explain these findings.

Chapter 7 - Discussion

With the ever-increasing rise in litigation arising through accidents in transport, industry and sports related activities, there is a growing need for the development of accurate and valid assessment tools and outcome measures. There is therefore an increasing interest in quantitative assessment of functional capacities. Humphreys presented a narrative review of four specific sensorimotor tests involving the cervical spine that show promise in the assessment of cervical function (Humphreys, 2008). Unfortunately, many of these tests are carried out in the sitting position and therefore do not take into consideration the role of cervical structures in maintaining postural stability and balance. For the last 30 years, one of the most popular laboratory systems for evaluating human postural stability is to measure spontaneous postural sway with the subject standing on a force platform (Bergenius et al., 1996, Masani et al., 2003). Although postural sway is widely recognised as an excellent measure of overall system health, it is unfortunately not a good measure of underlying pathophysiology since so many different disorders result in increased postural sway. Several modifications can be introduced to static posturography to render the balancing task more challenging for example, by reducing the size of the base of support, decreasing visual feedback (eye closure), decreasing proprioceptive feedback (compliant surface), or applying a secondary task while participants maintain their balance (Mancini and Horak, 2010). For example, higher mean velocity in the COP displacement has been associated with aging, neuropathy, Parkinson's disease, vestibular loss, stroke etc. The usefulness in using foam pads to decrease cutaneous plantar proprioception during posturographic measurement is fairly well established (Di Berardino et al., 2009, Chiang and Wu, 1997, Allum and Honegger, 1998, Liu and Kong, 2008). However, the types of foam pads used in previous experimentation had differed and it is difficult to compare results between studies.

The main objectives of this research were to 1) find out which optimal type of foam pads were the most effective to enhance postural disturbances according each participant's weight, and 2) measure the effects of various neck muscle groups fatigue on balance and on the perception of the subjective visual vertical (SVV) and subjective visual vertical (SVH). A secondary objective was to measure how subjects perceive their postural stability and exertion after neck muscle fatigue.

This chapter discusses the results of the experiments and whether the null hypotheses formulated at the onset of the projects were accepted or rejected. The relationship of the results to other literature is also discussed together with the practical implications of the findings on future assessments cervical functional capacities.

7.1 Foam pads

In this study, four different types of open cell foams were tested using an indentation test according to ASTM standard D-3574-95. In addition, thirty-six healthy male factory workers divided into three groups according to body mass were tested three times for each of the 13 randomly-selected experimental situations for changes in postural sway velocity in this cross-over study. The results showed that foam stiffness varied as the size of the indenter (i.e. the loading platform) changed. It demonstrated that foams pads, with the exception of the balance pad and the upholstery foam with the 406mm indenter, did not show linear deformation throughout the range of loads used in the MIRGL indentation test with both the 203mm and 406mm indenters. Both the memory foam pads failed to resist the compression at relatively low loads, which suggests they would not provide sufficient resistance to compression during posturography for healthy adult participants. Their force-displacement curves show an asymptotic behaviour beyond 220N for the memory foam and beyond 660N compression for the mono-layer upholstery foam, with non-linear stress-strain relationships observed due to the changes in the foam geometry at high strains. When the foam is highly compressed the foam volume tends to zero and the stiffness tends to infinity. Patel suggested that such large compression effects results in the participants being in too close contact with the rigid surface beneath the foam (Patel et al., 2008).

In contrast, the balance pad showed a largely linear response throughout the loads applied during the MIRGL test, while the upholstery foam exhibited a bi-linear type of behaviour when compressed with the 406mm diameter indenter. The latter supported the load with minimum deformation up to 660N, at which point it gave way and deformed with a lower stiffness up to the maximum load. Material properties of foam pad samples used in posturography have not been studied. Todd did report of the material properties of foam used on chairs during rehabilitation although the thin samples and the loads used were so small that comparisons are not possible (Todd et al., 1998). The findings of the present experiment become significant when posturography is performed. This is reported in the following section.

7.2 Foam pads and posturography

The basic principle of the force platform test is to measure the movements of the centre of pressure (COP) that reflect both the horizontal location of the centre of gravity (COG) and the reaction forces due to muscular activity (Era et al., 2006). The aim of data processing is to compute selected parameters of total body sway from the time series of COP positions. Typical parameters in platform measurements are the mean COP position (as a reference point), anterior-posterior and lateral sway, the length of the sway path, the sway area as well as sway velocity. COP mean velocity appears to be the parameter which shows the least variability and provide the most reliable estimate of COP (Lin et al., 2009). Sway velocity was therefore the balance parameter that was used in this study.

Here the effects of four different foam pads on balance was assessed. Participants were divided into three groups according to weight (Group 1: less than 60kg, n=5; Group 2: 60.1kg to 89.9kg, n=23; Group 3: greater than 90kg, n=8) The pads were either single or bi-layered (two different sizes of bi-layer surfaces) open-cell urethane memory foam (75mm and 100mm thickness), upholstery foam (100mm thickness) and closed-cell polyurethane foam (50mm thickness). The results showed that foam pads can indeed increase the postural sway velocity of healthy participants, in some cases significantly. When participant data were stratified according to mass, results showed that the balance pad produced the largest increase in sway velocity in Groups 1 and 2. In the heavier Group 3, the large bi-layer upholstery foam pad had the largest effect. The pairwise comparison between sway velocities without foam and with foam surfaces showed a large confidence interval, which can be attributed to the separation of participants into smaller groups according to mass. Furthermore, the participants were male factory workers with a mean BMI of 28 which is slightly higher than the UK male average (Finucane et al., 2011). Athletes presenting the same mass but with a more mesomorphic body type might have provided different results.

It is interesting to note that not only was there no significant difference between posturographic results between "no foam" and samples of 75mm and 100mm thick memory foam samples, but the sway velocity was somewhat improved when memory foam pads were used. A learning effect explanation can be excluded in view of the random order of the test conducted. It appears that, because the participants' feet had a smaller cross-sectional area than the pads onto which they were standing and they nearly flattened the pads, a shear force was created between the material and the sides of the feet as the specimen deformed (Figure 46, Todd et al., 1998).

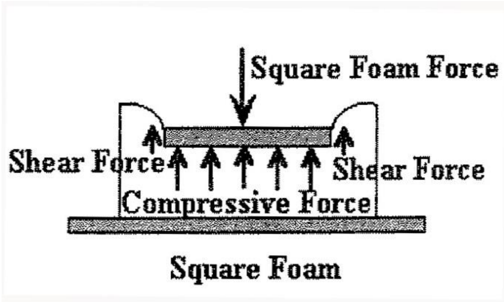

Figure 46 Example of shear force created between the material and the sides of the indenter as the specimen deformed. Adapted from Todd et al, 1998)

The effect is to increase the surface area of contact between the foam pads and the side of the feet, which in turn would most likely have increased proprioception thereby providing additional cues and improving balance. As a result, with participants of larger mass, as the deflection increased, the memory foam could actually have provided an advantage in the posturographic task (Figure 47).

Figure 47 Feet on 100mm memory foam pads show the shearing effect and the additional contact surface between the pad and the margin of the feet of a 96kg man

Thus, when selecting a type of foam pad to be used in posturography, it is recommended that investigators select samples appropriate to their participants' weight. For instance, in the selection of foam pads for individuals weighting more than 900N, a bi-layer upholstery foam pad with a density of the order of 37 kg/m^3 and Young's modulus of 45 kPa for a bi-layer upholstery foam and 217 kPa for the balance pad similar to that used in these experiments, could be the appropriate choice.

The results of the posturography experiments reported in Chapter 3 leads us to reject null hypothesis 1:

Four types of foam pads of different material properties used in static posturography do not increase the participant's sway velocity and centre of pressure displacement.

The different foam pads do indeed have different effects on the sway velocity exhibited by participants during quiet stance. The pads with a higher stiffness produced significant increases in postural sway velocity in participants with a mass of less than 90kg mass. Participants with mass larger than 90kg had the largest increase in postural sway velocity when a bi-layer pad was used. A bi-layer foam pad was used in subsequent studies to investigate the effects of neck muscle fatigue. Presently, Schieppati's study on neck muscle fatigue and balance is the only other publication where bi-layered pads are used (Schieppati et al., 2003).

7.3 Neck muscles fatigue

Fatigue development protocols in previous studies have either asked participants to resist loads of 25% or less maximum voluntary isometric contraction (MVIC) from 5 to 15 min, to 35% MVIC for 5 minutes (Schieppati et al., 2003, Edmondston et al., 2011, Stapley et al., 2006, Gosselin et al., 2004). However, a preliminary study showed that this level of activity was not sufficient to produce significant fatigue or a significant change in the EMG median frequencies in the present participants. It was assumed that this was due to the increased neck muscle strength found in healthy and fit elite amateur rugby league players compared to healthy non-athlete males (Gage et al., 2004, Hogrel et al., 2007). Therefore, the protocol was adapted here by raising the isometric contraction resisted load to 35% of MVIC as used by Stapley et al.

(2006) and Schieppati et al. (1999), and extending the contraction period to 15 minutes. Forty four (n = 44) healthy male players from the National Conference Rugby League premiership (age = 24 ± 2 years; weight = 91± 5.5kg, height = 1.84 ± 3.2cm) volunteered for inclusion in this cross-over design study. The neck muscles fatigue protocol involved having a head weight training harness placed on the participant's head, from which a cable extended horizontally (standardized between participants) and was attached via a pulley system to an adjustable mass. Eight different effort orientations were used each at 45° offset from the previous one. In order to decrease bias due to a participant's tiredness, the experiment was conducted over two days. Surface electromyography was used to assess changes in the median frequency over the contraction period.

The results confirm that this increased resistance torque produced the required signs of muscle fatigue as manifested by the significant EMG median frequency shift to lower frequencies over the course of the contraction. This shift was more prominent in muscles producing posterior movements such as E, RPO and LPO, which is interesting in view of the fact that all muscles contracted for the same amount of time and at the same percentage of MVIC. This could be explained by the difference in the amount of proprioceptive receptors in extensor and flexor muscles. The extensor muscles have a higher density, different distribution and morphology of muscle spindles in posterior sub-occipital muscle such as the superior oblique capitis, inferior oblique capitis and rectus capitis posterior major and minor sub-occipital muscles (Kulkarni et al., 2001). These muscles contain up to 100 times more muscle spindles than a muscle such as the trapezius which is one of the main cervical extensor muscle. This may explain their susceptibility to fatigue and, hence, their greater post-effect loss of proprioceptive function when fatigued (Boyd-Clark et al., 2002).

Assessment of neck muscle fatigue by postural sway velocity

As demonstrated in previous studies, fatigue of postural muscles, such as cervical, lumbar and lower limb extensor muscles, reduces the efficiency of postural mechanisms to a greater extent than non-postural muscles (Lin et al., 2009). Postural sway velocity and centre of pressure (COP) displacement were recorded before and after the neck muscle fatigue protocol. The results show that postural sway velocity increased after neck extensor muscle contraction which confirms that contraction duration and resistance were set correctly. Larger changes in postural sway velocity were observed when posterior muscle groups were fatigued (E; RPO; LPO). Whereas smaller changes in postural sway velocity were observed when anterior muscles were fatigued (F; RAO; LAO). These patterns of sway velocity changes where demonstrated by correspond to changes in EMG frequencies. Changes in cervical MF observed after 15 minutes 35% MVIC in eight different directions were thus reported for the time. Martin (2006) has shown that in upper arms during fatigue inputs from group III and IV muscle afferents from homonymous or antagonist muscles depress extensor motoneurons whereas motoneurons innervating flexors are facilitated (Martin et al., 2006). It is presently unknown if these findings are applicable to neck muscles. It is possible that neck muscle fatigue or other flexor muscle groups co-activating during the muscle contraction could have affected the sway velocity, as repetitive contraction during a fatigue protocol have been shown to alter postural characteristics (Tarantola et al., 1997, Choi, 2003). This could have produced a Type 1 error. Furthermore, changes in postural parameters sometimes occur after changes in the participants' position; therefore, any changes in the COP may have indirectly induced altered velocities (Schieppati et al., 1994). However, this was unlikely to occur in our study as the participants' feet and distance from the support pad were controlled for in all conditions. Recently, it has been demonstrated that initial frequency values provide information about the distribution of the muscle fibre types recruited at the beginning of the contraction. This relationship suggested that the slope of the EMG frequency changes was related to muscle fibre distribution in the muscle. Individual analysis also revealed a significant relationship between regression coefficients β1 (slope) and β0 (initial frequency) (Enoka and Duchateau, 2008). This observation although interesting is not relevant to the present project as the only interest regarding muscle contraction fatigue was to observe developing or progressive mechanical and physiological changes that are present before exhaustion secondary to a mechanical stress.

Posturography also provided information on the participants' COP post-effect displacement in the plane of contraction. "Postural post-effects" are increased body leaning associated with a change in postural reference resulting from a proprioceptive inflow as seen after fatiguing neck muscles. An increase in postural post-effect displacement, mainly in the sagittal plane, has been reported during short duration contraction of postural muscles (Duclos et al., 2004). In a further study, Duclos supported the hypothesis that the change in the postural reference was caused by the erroneous proprioceptive message produced by a sustained voluntary muscle contraction (Duclos et al., 2009). Conversely, Duclos' method differed significantly as he reported on the post-effects of just 30 second contractions and the fatigue protocol had participants sitting instead of standing. It has also been suggested that the effects observed in this study could be due to changes in the internal representation of the upper body following signs of muscle fatigue (Takahashi et al., 2006).

The results of this work showed that 15 minutes isometric contraction of various neck muscle groups at approximately 35% MVIC produced a significant change in the EMG median frequency in all positions and changed significantly the sway velocity in RPO, E and LPO. Therefore null hypothesis 2:

> *Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not change the muscles' myoelectric activity.*

and, null hypothesis 3:

Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect balance.

are both rejected.

Perceived effort and perceived postural sway

Participants were asked to rate their 1) perceived fatigue/exertion using the Rating of Perceived Exertion (RPE) Borg CR-10 scale and 2) perceived postural stability by using the same stability scale as used by Schieppati (Schieppati et al., 2003). There were variations between the ratings of perceived exertion, although the differences were not significant. We attribute this situation to the methodology used whereby loads were calculated as a percentage of the respective muscle's MVIC. Absence of change in perceived effort after neck muscles contraction has also been reported in a study on military helicopter flight crews (Harrison et al., 2009). Pilots were asked to perform 70% MVIC efforts for a maximum of 180 seconds in flexion, extension and right and left lateral flexion. No statistically significant differences were found between RPE for the four isometric contraction trials ($p=0.81$). The lack of change in perceived effort is unusual in non-elite athletes as there is a wide variation in perceived subjective muscle fatigue in the general population (Dedering et al., 1999, Troiano et al., 2008, Veldhuizen et al., 2003). This finding could be explained by our sample of participants who were highly trained elite athletes, including three that had played previously as professionals in the UK Rugby Super League. Furthermore, the Borg CR-10 scale results showed that after 15 minutes contraction the perceived effort was scored at less than seven for nearly all participants which indicated that the effort produced, although perceived as difficult, was relatively well tolerated by most. Nonetheless, increased perceived postural sway was more pronounced after posterior and laterally oriented isometric contractions than after contraction of the anterior group of muscles. This perceived instability did not relate to the perceived effort or changes in EMG frequency. If we assume that central factors controlling muscle contraction are equal for the various muscle groups used in this study, differences in postural stability and EMG signal must be attributed to local muscular mechanisms.

Rugby union neck injury incidence occur mostly in the scrum, tackle and rucks and mauls and can be nearly 10 per 1000 player hours for mixed populations, although there is still a scarcity of severity and analytical data (Swain et al., 2011). Rugby league incidences of neck and spinal injuries differ, as most of the injuries occur during tackle and occur in 2.9 per 100,000 players hours (King et al., 2011). The long-term significance of these injuries can be seen in many of these players, who will show evidence of early degenerative changes from as early as 21 years of age (Castinel et al., 2010). In addition to structural changes, players can display persistent functional disturbance, such as altered eye movement control, kinaesthetic sensibility or other symptoms of postural control, such as altered balance or the perception of the visual vertical and horizontal (Treleaven, 2008, Humphreys, 2008). Therefore occult pre-existing degenerative conditions in our sample of rugby players might have influenced the results.

We followed on the present project by investigating the effects of cervical muscle fatigue on the participant's perception of visual vertical. This hopefully will have contributed further to form the basis of a more comprehensive and controlled battery of tests that could help scientists understand dysfunctional mechanisms produced secondary to neck injuries.

7.4 Neck muscle fatigue and the computerised dot and frame test (C-RFTdot)

As seen in the previous section, induced neck muscle fatigue has been shown to alter functional capacities such as balance. The Rod and Frame Test has also shown promise as a method of assessing the effects of chronic neck pain and injury. The objectives of this project were therefore 1) to validate the

computerised rod and frame test in the standing posture, and 2) to measure the effects that different cervical muscle fatigue protocol would have on the assessment of the subjective visual vertical and horizontal. The neck fatigue protocol described previously was applied to the participants (n=56) before taking the Rod and Frame test where participants were presented with different combinations of dots and frames over four repetitions. The parameters analysed were the changes in horizontal and vertical rod and frame test between the neutral and all different directions of contraction. The changes of recorded unsigned vertical and horizontal errors for the combined frame condition in all situations of isometric contraction were also analysed.
The results showed that participants obtained highly correlated scores on the C-RFT^{dot} whilst sitting or standing; nonetheless, this did not confirm agreement between the two methods. The Bland-Altman test was designed specifically to test such an agreement between two experimental methods (Bland and Altman, 1986, Bland and Altman, 2010). Therefore, we considered both sitting and standing situations as field methods and plotted differences against their mean value. (Since we were comparing different test positions, it was not considered appropriate to assign the sitting position as the reference "Gold Standard" and plot differences against that (Mantha et al., 2000)).

Bagust (Bagust et al., 2005) found no significant difference between the no frame and frame at 0° (frame^{0}) whilst testing participants in the sitting position. Our results indicate that even without a frame or in the presence of a frame^{0}, fatiguing neck muscles do indeed affect the participant's ability to perceive accurately the subjective vertical and horizontal in all directions of contraction, except after contractions in the sagittal plane (extensor and flexion). Panichaporn also reported this absence of significant change after fatiguing neck extensor muscles at 33.3% MVIC for five minutes (Panichaporn et al., 2013). It is interesting to note that although neck extensor and flexor muscles fatigue did not change the C-RFT^{dot} results, the muscles themselves are quite different from each other both in structure and function. As mentioned earlier, the density of muscle spindles is higher in the small intrinsic, deep dorsal and suboccipital cervical muscles than in other cervical muscle groups which accounts for their important role in proprioception (Peck et al., 1984, Rix and Bagust, 2001). In addition, even though 15 minutes of muscle contraction did increase the errors recorded in the plane of contraction when a frame was present, contrary to other studies, there was no significant difference in the direction of errors recorded (Docherty et al., 2012, Docherty and Bagust, 2010). This phenomenon is reminiscent of motor post-effects seen after short duration isometric contractions (Duclos et al., 2004). The neurophysiological processes underlying these observations are unknown but are similar to observed displacement along the same plane seen in the Kohnstamm phenomenon (Ivanenko et al., 2006).

These findings suggest three main effects. Firstly, proprioception alone cannot explain the difference in C-RFT^{dot} scores between muscles fatigued in the sagittal plane and muscles fatigued in the frontal or oblique planes. This is supported by Funabashi's findings that the use of a neck brace does not provide sufficient afferent input to change a healthy subject's perception of visual verticality (Funabashi et al., 2011). Additional support for the visual inputs overriding cervical proprioception has been demonstrated in various studies (Karnath et al., 2002, Golomer et al., 2005).

Secondly, these results also support the rejection of the standard model of peripheral fatigue as inadequate to explain the selective effects on the C-RFT^{dot} scores (Noakes et al., 2005). Finally, we suggest that the absence of effects after contractions of muscles in the sagittal plane may be related to an evolutionary advantage of developing improved subjective verticality awareness in the same direction as the main visual field even in the presence of disturbances such as muscle fatigue or injury. It has been reported since the early twentieth century that maximum acuity occurred with horizontal and vertical orientation (Emsley, 1925). Latto suggested that the dominance of visual orientation in perception was due to the fact that more Hubel and Wiesel orientation detectors (in the visual cortex) were turned to the horizontal and vertical than to oblique lines and edges (Atto and Russel-Duff, 2002). The improved perception of vertical has also been reviewed in the discussion of bipedalism in chimpanzees and hominids, where it has been suggested that this developed mechanism in demanding positions relies on an innate spatial gravitational self-awareness in relation to the ground reaction force (Stanford, 2006, Skoyles, 2006).

Recently, Takasaki studied the minimum repetitions for stable measures of visual dependency using the C-RFT^{dot} (Takasaki et al., 2012). He concluded that instead of the usual four repetitions, five should be used so that the C-RFT^{dot} can provide consistent measures of deviation from the vertical in asymptomatic healthy individuals. However, during the validation part of our project using four repetitions, we consistently obtained comparable results to previous C-RFT^{dot} reports (Docherty et al., 2012, Docherty and Bagust, 2010). The higher minimum numbers of repetitions reported by Takasaki could be due to the additional visual feedback provided to their participants by the modified computer program they used in their experiment. Instead of presenting participants with just a white tilted/untilted square frame and two dots on a black background, Takasaki added a control panel interface on the screen with which the participants were required to move the dots by dragging and turning a button created on the lower right screen using a computer mouse. This additional object in the visual field represents a significant difference in the methods used because the previous C-RFT^{dot} studies have attempted to minimise participants' visual cues whilst Takasaki actually increased visual cues. Therefore, we feel confident that our results are a true representation of the participants' true capacities.

It has been demonstrated that high-level athletes participating in open-skills activities specifically involving contact were more field-dependant compared to medium level athletes (Liu, 2003, Liu, 1996). Our participants did not appear to be particularly field-dependant, although their results showed less variance than previous C-RFT^{dot} studies. This could be attributed to the highly homogenous group of participants playing mostly the same sport with similar age, skills and level of fitness compared with previous studies presenting more heterogeneous volunteers.

Our results show that, in our participants, different muscle groups react differently to disturbances such as isometric muscle contraction. We already know that balance is altered after neck extensor muscle fatigue (Schieppati et al., 2003, Duclos et al., 2009, Gosselin et al., 2004) or after whiplash injuries (Stapley et al., 2006, Field et al., 2008). What remains unknown is the effect of injuries to specific muscles groups on these functional properties. As demonstrated in the previous chapters, our results show a clear trend from the highest change in velocity after posterior muscle groups were contracted (E, ROA, RPO) towards the lowest velocity change after flexor muscles contraction (F, LAO, RAO). These results are quite striking when placed in context with the present study as we observe for the first time that neck flexor and extensor muscle groups do not appear to play a significant role in our space awareness abilities as initially thought. We have shown that extensors and lateral flexors appear to be major contributing factors to cervical functional capacities. These findings represent important new elements that should be investigated further in order to develop clear outcome and rehabilitation protocols.

In view of these results, null hypothesis 4:

Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect the subjective perception of vertical.

null hypothesis 5:

Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect the subjective perception of horizontal.

null hypothesis 6:

Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect the subjective perception of horizontal

and null hypothesis 7:

Contracting neck muscles at 35% maximum isometric contraction in any one of eight specific directions does not affect the subjective perception of fatigue

are all rejected.

Fatiguing neck muscles affect the participants' ability to perceive accurately the subjective vertical and subjective horizontal in all directions of contraction, except after contractions in the sagittal plane (extensor and flexion). Furthermore, 15 minutes isometric contraction of various neck muscle groups at approximately 35% MVIC did produce a change in the subjective perception of fatigue. Conversely, the reported perception of effort was not significantly different between directions of contraction. Participants perceived increased postural sway after being submitted to a neck fatigue protocol. This supposed change was more pronounced after posterior and laterally oriented isometric contractions.

7.5 Study limitations

A possible source of error in this project could originate from the equipment used. In 2012 Golriz examined both the test-retest reliability of the Midot force plate to explore the effect of using the mean value from multiple repetitions on reliability, and she examined the concurrent validity of postural control measures obtained (Golriz et al., 2012b, Golriz et al., 2012a). The reliability was acceptable when averaging multiple repetitions as in the present project. On the other hand, there was poor concurrent validity from the Midot force platform when compared to one other portable force plate (Accugait, AMTI, Watertown, MA, USA). These poor results could be due to methodological weaknesses from Golriz' study such as using only one 20 kg "certified weight" whilst the validation and reliability procedures of this thesis used discs of seven different weights (2.5 kg, 5kg, 10 kg, 12.5 kg, 15 kg, 20kg, 25kg) that were placed in combination on the force platform (Table 3). Furthermore, there were other important limitations to the study such as 1) sampling limited to university students, 2) no attempt to assess the validity with eyes closed, 3) no assessment of the validity when larger sway patterns were caused by external perturbation such as neck fatigue, 4) sampling rates of both platforms were different (Midot: 200Hz, AMTI: 100Hz), 5) the Midot force platform's validity was tested against only one other portable system, 6) no foam pads were used during the validity study, 7) the software used to analyse the Midot force platform data is not mentioned. In view of the validation study limitations, the Midot force platform continued to be used in experiments included in this thesis. Pertinent conclusions can still be drawn from the results because one of the main objectives of the thesis was to assess changes due to muscle fatigue protocol.

The limited number of different foam pads studied represents another limitation of the present thesis. The selection of the foam pads used in this thesis was determined on the observable pads differences in weight and texture which represented an acceptable range of readily available products. Additional samples of varied modulus of elasticity and thickness might have provided results that would have produced larger postural sway velocities.

The standing neck fatigue protocol was adapted from previously used methods (Stapley et al., 2006, Schieppati et al., 2003). Others have developed neck muscle fatigue protocols where the participants position was different such as sitting (Gosselin et al., 2004, Thuresson et al., 2005) , or lying down (Edmondston et al., 2011). The neck fatigue protocol used in this thesis would appear to be the one presenting the least stimulation from external factors by limiting contact with other parts of the body. Nonetheless, the hand held mouse, the chest pad onto which the participants' thorax was leaning against, the head harness, and the video goggles could have produced afferent stimulation that could have potentially skewed the results.

As described previously, dynamic posturography (moving platform posturography) is an excellent method to objectively quantify and differentiate among a wide variety of possible sensory, motor and centre adaptive impairments to balance control. Using static posturography is not a limiting factor as such as it is unlikely that testing participants by dynamic posturography after submitting them to a neck fatigue protocol would have produced different results. On the other hand, use of moving force platform with alter visual cues could have provided additional relevant information.

The present studies had such homogeneous samples (participants) that it also avoided most of the confounding variables such as gender and age that make studies involving participants more complex. Although this is one of the study's strength, the conclusion from the studies involving the neck muscle fatigue must be limited to healthy young professional rugby league athletes.

Chapter 8 - Conclusions and suggestions for future work

The aim of this project was to contribute to the general knowledge of neck functional capacities with the view to ultimately helping in the development of improved neck injuries management outcomes measures. The literature review identified key gaps in the current knowledge, and guided the direction of the research undertaken. In particular, the following were investigated 1) which type of foam pads used during static computerised posturography are the most effective to enhance postural disturbances, taking into consideration the participant's weight, and 2) what are the effects of various neck muscle groups fatigue on balance and on the perception of the subjective visual vertical and horizontal?

Firstly protocols were devised to assess the validity, reliability and the material properties of the equipment to be used in the experimentation. Secondly, the effects of different surfaces were measured using the portable force platform with velocity of postural sway being the posturographic parameter analysed. The next experiment involved the measurement of the effect of sustained isometric cervical muscle contraction in eight different directions on balance and perceived stability in addition to the measurement of subjects' perception of fatigue and subjects' perception of change in balance. The muscle fatigue protocol involved the use of an adjustable mass held in a static position by the neck muscles over a certain period of time. In the last experiment, the Computerised Dot and Frame (C-RFT^{dot}) test was validated in the standing posture, and used to measures the effects of cervical muscle fatigue on field-dependency. Finally, the findings were critically examined in relation to the previous state of the subject, and significant findings were highlighted.

In summary, this thesis suggests that the selection of foam pads for posturography could possess 1) a modulus of elasticity of 45 kPa for a bi-layer upholstery foam and 217 kPa for the balance pad and 2) provide minimal deflection under the participants' load. The results also show that fifteen minutes of constant neck muscle activity, at around 35% MVIC in eight different directions in the standing position, produced significant altered and perceived altered balance. The median frequency EMG and sway velocity were most affected during posteriorly oriented contractions. Furthermore, after muscle contraction, there were significant increases in horizontal and vertical errors on the C-RFT^{dot} results in all participants, except after efforts in neck flexion. These errors were predominantly present after fatigue of muscles in the coronal plane of contraction. It was concluded therefore that neck flexor and extensor muscle groups do not appear to play a significant role in our space awareness abilities. Interestingly however, extensors and lateral flexors appear to be major contributing factors to cervical functional capacities such as balance.

Thus this thesis has addressed issues that relate to assessment of neck functional capacities. Although this is a relatively recent field of investigation, certain functional parameters have been shown to have potential in the future development of cervical outcome measures.

Where to go from here

A fundamental requirement for many activities of daily living is the ability to perform 'work', i.e. in bioengineering terms, the ability to apply a force to an object and cause displacement of that object. Such activities require the integrated efforts of the muscles, ligament, skeleton and nervous system in order to produce the necessary forces to produce movement. Thus, the assessment of functional capacities provides important diagnostic and prognostic information in a wide variety of clinical settings. Furthermore, numerous clinical trials, especially those in people that have sustained injuries or suffered from chronic pain have used various functional capacity tests as a primary or secondary end point. This thesis reveals how two different functional capacity measures are affected by neck muscle fatigue. Note, the studies used a homogeneous group of participants, thereby avoiding most of the normal confounding variables such as gender and age that make studies involving participants more complex. The method shows promise and it is now recommended to extend the range of other categories of homogeneous groups such as sedentary people, highly field-dependent and field independent individuals, different age groups, different body types, and eventually individuals that suffer from musculoskeletal complaints or that have been involved in traumatic incidents. Obviously, these studies should all be repeated with other homogeneous groups such as female participants.

A new version of the C-RFT^{dot} test is in development with additional features that might fine tune the assessment (for example, variable colour and brightness of the dots and background, and variable rotation speeds). These features will need to be investigated in order to determine which if any of these changes, help improve discrimination of the studied parameters. The present thesis attempted to reduce proprioceptive feedback during the C-RFT^{dot} by having the participants take the test in the standing position whilst using a handheld computer mouse. Recently a number of companies have scaled back medical grade EEG technology to create inexpensive brain-computer interfaces (BCIs). This technology has been built into prosthetics, toys and gaming devices and it could certainly be adapted to control the C-RFT^{dot} equipment. This could potentially eliminate any remaining proprioceptive cues provided by the handheld mouse.

Using participants as their own control in a cross-over study with random order of intervention represents an effective and cost-effective method to obtain quality data. In view of the interesting results obtained in this project, it would be indicated to repeat the experiments by adding a control group in order to strengthen the obtained conclusions. Furthermore, in order to decrease boredom of standing still for the duration of sampling, experimentation could be divided into additional days.

The application of a neck muscles fatigue protocol on various neck muscles is time consuming and impractical to apply in a clinical setting. As described in the review of the previous literature, vibratory stimulation of muscles over a relatively short time also alters functional capacities. Comparative studies between the muscle fatigue protocol or specific muscle groups and the use of vibration stimulation of the corresponding muscles on balance and on the C-RFTdot should also be performed. The results may show similar results for a significant shorter sampling time thereby facilitating the development of clinical tests.

Lastly, performing the battery of tests available with computerised dynamic posturography (moving force platform and changing visual input) in conjunction with the present neck muscle fatigue protocol may provide additional information.

Finally, in view of the fact that both the balance test and the C-RFT^{dot} appeared to provide useful results after cervical muscle contraction, the development of a combined test whereby both functional capacities could be tested simultaneously would be useful. This would decrease the time allocated for testing and could therefore decrease participants' fatigue with its corresponding bias of results.

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Annexe

- Consent
- Foam testing standard: ASTM test D-3574-11
- Publications
- Brief description of statistical tests used

Consent

Ethical approval was granted by the School of Engineering, University of Hull. Participants in each experiment were presented with a specific information sheet to that particular project and they were asked to read and sign a consent form.

Experiment 1 – Relationship between various foam pads, body weight and balance

EXPERIMENT 1	PARTICIPANT INFORMATION SHEET

Study Title: Relationship between various foam pads, body weight and balance

Study Host: University of Hull, Engineering Department

Principal Investigator: Guy Gosselin

Location of Study: East Yorkshire Chiropractic Clinics

Introduction

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and ask the principal investigator, Guy Gosselin, if there is anything that is not clear or if you would like more information.

Consumers for Ethics in Research (CERES) publish a leaflet entitled "Medical Research and You". This leaflet gives more information about medical research and looks at some questions you may want to ask. A copy may be obtained from CERES P.O. BOX 1365, London, N10 0BW.

Purpose of the Study

The study will measure how different types of foam pads placed on a force platform will affect balance differently for participants of different body weight.

Am I eligible to volunteer?

YES is you fit ALL these criteria	NO if you fit ANY of these
.18-60 years old . no history of neck trauma . no spinal pain in past 6 months . not under any form of treatment for neck or lower limbs in past 6 months . no learning difficulties, severely ill, or disabled individuals . stand immobile with your eyes closed	. older than 60 years old or younger than 18 years old . history of neck trauma or balance problems . neck pain or lower legs pain in last 6 months . has received spinal care in last 6 months . has learning difficulties, severely ill, or disabled individuals

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are still free to withdraw at anytime and without giving reason.

What will happen to me if I take part?

You will be required to attend the examination room for assessment on 1 occasion.

The test involves standing with eyes closed on an electronic weight scale for 20 seconds 55 times. A 15 minutes break will be allowed twice during the experiment.

Will my taking part in this study be kept confidential?

All information collected about you will be kept confidential and will only be available to the Principal Investigator. It will not be made available to any third party. It will be stored on paper and on a computer and destroyed at the end of the study. Any information that is published will have your name removed so that you cannot be recognised from it.

Is this study likely to cause me any harm?

No. There are no risks of suffering any harm by participating in this project.

Is this study likely to cause any discomfort or distress?

It is unlikely that this study should cause you any discomfort or distress.

What will happen to the results of the research?

The results of the study will be published. A copy of the results can be obtained from the Principal Investigator.

Who is organising and funding the research?

The study forms the basis of a PhD thesis being prepared by the Principal Investigator registered at the University of Hull's Engineering Department.

Who has reviewed the study?

The University of Hull's Engineering Department Ethics Committee have reviewed the project.

Who to contact for further information?

Guy Gosselin
431 Holderness Road
Hull

Tel: 01482 334400

Thank you for participating in this study.

This information sheet is for you to keep together with a copy of the signed patient consent form.

Study Title: Relationship between various foam pads, body weight and balance

Study Host: University of Hull, Engineering Department

Principal Investigator: Guy Gosselin

Location of Study: East Yorkshire Chiropractic Clinics

I confirm that I have read and understand the information sheet on the above study and have had the opportunity to ask questions.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

I understand that the data collected during this experiment will be analysed by the Principal Investigator.

I agree to take part in the above study.

Participant information and signature:

First name ________________ Surname _______________ D.O.B _________

Today's Date _____________ Signature _______________________________

Name of person taking consent:

First name _______________ Surname ________________________________

Today's Date ___________ Signature _________________________________

1 copy for subject; 1 copy for researcher

Experiment 2 - Effects of neck muscle fatigue on Balance

Study Title: Effect of neck muscle fatigue on balance

Study Host: University of Hull, Engineering Department

Principal Investigator: Guy Gosselin

Location of Study: East Yorkshire Chiropractic Clinics

Introduction

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and ask the principal investigator, Guy Gosselin, if there is anything that is not clear or if you would like more information.

Consumers for Ethics in Research (CERES) publish a leaflet entitled "Medical Research and You". This leaflet gives more information about medical research and looks at some questions you may want to ask. A copy may be obtained from CERES P.O. BOX 1365, London, N10 0BW.

Purpose of the Study

The study will measure the effects of fatiguing your neck muscles on balance.

Am I eligible to volunteer?

YES is you fit ALL these criteria	NO if you fit ANY of these
.18-30 years old . no history of neck trauma . no spinal pain in past 6 months . not under musculoskeletal care in past 6 months . no learning difficulties, severely ill, or disabled individuals . from a prone position, subjects must be able to lift their head off the couch without difficulty	. older than 30 years old . younger than 18 years old . history of neck trauma . spinal pain in last 6 months . has received spinal care in last 6 months . has learning difficulties, severely ill, or disabled individuals

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are still free to withdraw at anytime and without giving reason.

What will happen to me if I take part?

You will be required to attend the examination room for assessment on 2 separate occasions. On every occasion, a head band will be placed around your head and a weight will pull your head in a certain direction. You will be asked to maintain the head and neck in a neutral position for 15 minutes. The activity of the muscles of your neck will be monitored during this time using small self-adhesive pads applied to the skin over the muscles in the neck.

The test involves standing with eyes closed on an electronic weight scale for 30 seconds..

Will my taking part in this study be kept confidential?

All information collected about you will be kept confidential and will only be available to the Principal Investigator. It will not be made available to any third party. It will be stored on paper and on a computer and destroyed at the end of the study. Any information that is published will have your name removed so that you cannot be recognised from it.

Is this study likely to cause me any harm?

No. There are no risks of suffering any harm by participating in this project.

Is this study likely to cause any discomfort or distress?

It is unlikely that this study should cause you any discomfort or distress.

Although unlikely, you may experience some discomfort while you apply a gentle force on the exercise machine.

The Principal Investigator, Guy Gosselin, will be present at all times during the experimentation is taking place. At any point, if any of these symptoms appear, you must immediately tell the person closest to you that you are feeling neck discomfort.

What will happen to the results of the research?

The results of the study will be published. A copy of the results can be obtained from the Principal Investigator.

Who is organising and funding the research?

The study forms the basis of a PhD thesis being prepared by the Principal Investigator registered at the University of Hull's Engineering Department.

Who has reviewed the study?

The University of Hull's Engineering Department Ethics Committee have reviewed the project.

Who to contact for further information?

Guy Gosselin
431 Holderness Road
Hull

Tel: 01482 334400

Thank you for participating in this study.

This information sheet is for you to keep together with a copy of the signed patient consent form.

Study Title: Effect of neck muscle fatigue on balance

Study Host: University of Hull, Engineering Department

Principal Investigator: Guy Gosselin

Location of Study: East Yorkshire Chiropractic Clinics

I confirm that I have read and understand the information sheet on the above study and have had the opportunity to ask questions.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

I understand that the data collected during this experiment will be analysed by the Principal Investigator.

I agree to take part in the above study.

Participant information and signature:

First name _______________ Surname _______________ D.O.B __________

Today's Date ____________ Signature ______________________________

Name of person taking consent:

First name _______________ Surname ________________________________

Today's Date ___________ Signature ________________________________

1 copy for subject; 1 copy for researcher

Experiment 3 - Effects of cervical muscle fatigue on the perception of the subjective vertical and horizontal

EXPERIMENT 3	PARTICIPANT INFORMATION SHEET

Study Title: Effect of cervical muscle fatigue on the perception of the subjective vertical and horizontal

Study Host: University of Hull, Engineering Department

Principal Investigator: Guy Gosselin

Location of Study: East Yorkshire Chiropractic Clinics

Introduction

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and ask the principal investigator, Guy Gosselin, if there is anything that is not clear or if you would like more information.

Consumers for Ethics in Research (CERES) publish a leaflet entitled "Medical Research and You". This leaflet gives more information about medical research and looks at some questions you may want to ask. A copy may be obtained from CERES P.O. BOX 1365, London, N10 0BW.

Purpose of the Study

The study will measure the effects of fatiguing your neck muscles on the perception of the subjective vertical and horizontal.

Am I eligible to volunteer?

YES is you fit ALL these criteria	NO if you fit ANY of these
.18-30 years old . no history of neck trauma . no spinal pain in past 6 months . not under musculoskeletal care in past 6 months . no learning difficulties, severely ill, or disabled individuals . from a prone position, subjects must be able to lift their head off the couch without difficulty	. older than 30 years old . younger than 18 years old . history of neck trauma . spinal pain in last 6 months . has received spinal care in last 6 months . has learning difficulties, severely ill, or disabled individuals .wear spectacles

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving reason.

What will happen to me if I take part?

You will be required to attend the examination room for assessment on 2 separate occasions. On every occasion, a head band will be placed around your head and a weight will pull your head in a certain direction. You will be asked to maintain the head and neck in a neutral position for 15 minutes.

The test involves standing and you will be asked to look into video goggles and align dots on the screen with either the vertical or horizontal. You will control the bar with a hand held computer mouse while your arms will be at your side.

Will my taking part in this study be kept confidential?

All information collected about you will be kept confidential and will only be available to the Principal Investigator. It will not be made available to any third party. It will be stored on paper and on a computer and destroyed at the end of the study. Any information that is published will have your name removed so that you cannot be recognised from it.

Is this study likely to cause me any harm?

No. There are no risks of suffering any harm by participating in this project.

Is this study likely to cause any discomfort or distress?

It is unlikely that this study should cause you any discomfort or distress.

Although unlikely, you may experience some discomfort while you apply a gentle force on the exercise machine.

The Principal Investigator, Guy Gosselin, will be present at all times during the experimentation is taking place. At any point, if any of these symptoms appear, you must immediately tell the person closest to you that you are feeling neck discomfort.

What will happen to the results of the research?

The results of the study will be published. A copy of the results can be obtained from the Principal Investigator.

Who is organising and funding the research?

The study forms the basis of a PhD thesis being prepared by the Principal Investigator registered at the University of Hull's Engineering Department.

Who has reviewed the study?

The University of Hull's Engineering Department Ethics Committee have reviewed the project.

Who to contact for further information?

Guy Gosselin
431 Holderness Road
Hull

Tel: 01482 334400

Thank you for participating in this study.

This information sheet is for you to keep together with a copy of the signed patient consent form.

Study Title: Effect of cervical muscle fatigue on the perception of the subjective vertical and horizontal

Study Host: University of Hull, Engineering Department

Principal Investigator: Guy Gosselin

Location of Study: East Yorkshire Chiropractic Clinics

I confirm that I have read and understand the information sheet on the above study and have had the opportunity to ask questions.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

I understand that the data collected during this experiment will be analysed by the Principal Investigator.

I agree to take part in the above study.

Participant information and signature:

First name ______________ Surname ______________ D.O.B __________

Today's Date ____________ Signature ______________________________

Name of person taking consent:

First name ______________ Surname ______________________________

Today's Date ___________ Signature ______________________________

1 copy for subject; 1 copy for researcher

Designation: D3574 − 11

Standard Test Methods for Flexible Cellular Materials—Slab, Bonded, and Molded Urethane Foams[1]

This standard is issued under the fixed designation D3574; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (´) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 These test methods apply to slab, bonded, and molded flexible cellular products known as urethane foams. Urethane foam is generally defined as an expanded cellular product produced by the interaction of active hydrogen compounds, water, and isocyanates.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3 The values stated in SI units are to be regarded as standard.

NOTE 1—There is no known ISO equivalent to this standard, however certain test methods in this standard have similar or equivalent ISO standards and are listed in the scope of the individual test method sections.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

D624 Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers

D737 Test Method for Air Permeability of Textile Fabrics

D3576 Test Method for Cell Size of Rigid Cellular Plastics

D3675 Test Method for Surface Flammability of Flexible Cellular Materials Using a Radiant Heat Energy Source

E162 Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source

E662 Test Method for Specific Optical Density of Smoke Generated by Solid Materials

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *bonded foam*—a product produced by the adhesion of small pieces of urethane foam to each other with a suitable bonding agent.

3.1.2 *core*—the internal portion of a molded part, free of skin.

3.1.3 *cored foam*—a flexible cellular material containing a multiplicity of holes (usually, but not necessarily, cylindrical in shape), molded or cut into the material in some pattern, normally perpendicular to the foam rise direction, and extending part or all the way through the piece.

3.1.4 *convoluted foam*—a flexible cellular material specially cut into sheets with "egg carton"-like dimples. The dimple peaks and bases can have varied shapes and dimensions.

3.1.5 *flexible cellular product*—a cellular organic polymeric material that will not rupture when a specimen 200 by 25 by 25 mm is bent around a 25-mm diameter mandrel at a uniform rate of one lap in 5 s at a temperature between 18 and 29 °C.

3.1.6 *molded foam*—a cellular product having the shape of the enclosed chamber in which it is produced by foaming.

3.1.7 *skin*—the smooth surface layer of a molded foam product, formed by contact with the mold or surfaces.

3.1.8 *slab*—a section of foam that is cut from the internal portion of a large bun.

3.1.9 *urethane foam*—a flexible cellular product produced by the interaction of active hydrogen compounds, water, and isocyanates.

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[1] These test methods are under the jurisdiction of ASTM Committee D20 on Plastics and are the direct responsibility of Subcommittee D20.22 on Cellular Materials - Plastics and Elastomers.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.10 *viscoelastic foam*—a specially formulated urethane foam characterized by having slow recovery, low resilience, and high hysteresis loss.

3.1.11 *cell count*—a measurement used to characterize different types of foams based on the size of the individual cells in the foam matrix, typically expressed as either average cell diameter or as the number of cells per linear distance. For measuring cell counts, see Test Method D3576

***A Summary of Changes section appears at the end of this standard**

3.1.12 *clickability*—the ability of a flexible cellular material to recover from the pinching effects of die cutting.

4. Summary of Test Methods

4.1 Unless specifically stated otherwise between the supplier and the purchaser, all tests shall be made in accordance with the methods specified in Sections 9-133 which include test procedures for the following:

Tests:		Sections
Test A	Density Test	9-15
Test B_1	Indentation Force Deflection Test—Specified Deflection (IFD)	16-22
Test B_2	Indentation Residual Gauge Length Test—Specified Force (IRGL)	23-29
Test C	Compression Force Deflection Test	30-36
Test D	Constant Deflection Compression Set Test	37-44
Test E	Tensile Test	45-52
Test F	Tear Resistance Test	53-60
Test G	Air Flow Test	61-67
Test H	Resilience (Ball Rebound) Test	68-75
Test I_1	Static Force Loss Test at Constant Deflection	77-85
Test I_2	Dynamic Fatigue Test, Roller Shear	86-94
Test I_3	Dynamic Fatigue Test, Constant Force Pounding	95-103
Test I_4	Dynamic Fatigue Test, Carpet Cushion	104-112
Test I_5	Dynamic Fatigue Test, Constant Deflection Pounding	113–121
Aging Test J	Steam Autoclave Aging	122-127
Aging Test K	Dry Heat Aging	128-133
Aging Test L	Wet Heat Aging	134-139
Test M	Recovery Time	140-145

Appendixes:

X1. Suggested Method for Specifying Flexible Urethane Foams
X2. Suggested Method of Construction for a Roller Shear Dynamic Flex Fatigue Apparatus
X3. Definitions of Terms Used to Describe the Force-Deflection Curve of Flexible Urethane Foam
X4. Suggested Tests for Determining Combustibility of Flexible Urethane Foam. (The combustion tests are given for informational purposes only and are not part of the standard.)
X5. Suggested Method for Verification of an Inclined Oil Manometer
X6. Suggested Method for Measuring Hysteresis Loss of Foams

5. Significance and Use

5.1 The test procedures provide a standard method of obtaining data for research and development, quality control, acceptance and rejection under specifications, and special purposes.

5.2 The data obtained by these test methods are applicable to the material under conditions of the particular test and are not necessarily the same as obtained in other environments in use.

6. General Test Conditions

6.1 Tests shall be conducted under known conditions of temperature and humidity or as specified in the individual test procedure. The product shall be conditioned undeflected, and undistorted at the temperature and humidity of test for at least 12 h before being tested. In cases of dispute, the tests shall be made at a temperature of 23 6 2°C and in an atmosphere of 50 6 5 % relative humidity.

6.2 It is recommended for referee purposes that all tests shall be performed 7 days or more after the foam has been manufactured.

6.3 For mechanical tests, it is advisable to carefully select the proper load cell for each test. It is recommended that the expected load for any individual test falls within 10-90 % of the load cell capacity.

7. Sampling

7.1 When possible, the completed manufactured product shall be used for the test specified. Representative samples of the lot being examined shall be selected at random as required.

7.2 When it is necessary or advisable to obtain specimens from the articles, as in those cases where the entire sample is not required or adaptable for testing, the method of cutting and the exact position from which specimens are to be taken shall be specified. The density and the state of cure can vary in different parts of the finished product, especially if the article is of complicated shape or of varying thickness, and these factors affect the physical properties of the specimens. Also, the density is affected by the number of cut surfaces on the specimen. If a test specimen is die cut, ensure that the sides are not concaved and allow sufficient time for complete recovery of the thickness across the full width of the specimen before testing.

7.3 When the finished molded product does not lend itself to testing or to the taking of specimens because of complicated shape, small size, metal or fabric inserts, adhesion to metal, or other reasons, molded test slabs as agreed upon between the supplier and the purchaser shall be prepared.

7.4 When differences in test results arise due to the difficulty in obtaining suitable specimens from the finished parts, the supplier and the purchaser shall agree upon an acceptable location to take the specimen.

8. Measurement of Test Specimens

8.1 Measure the length and width with a scale, tape, or caliper gauge. Take care not to distort the foam.

8.2 Measure thickness up to and including 25 mm using a height or electronic display gauge with a minimum foot area of 650 mm². Hold the pressure of the gauge foot to a maximum of 800 Pa (see Note 2). Thicknesses over 25 mm shall be measured with a height or electronic display gauge, a sliding caliper gauge, or as specified in 8.1. When a sliding caliper gauge is employed, make the gauge setting with the gauge out of contact with the foam. Pass the specimen through the previously set gauge; the proper setting shall be the one when the measuring faces of the gauge contact the surfaces of the specimen without compressing it.

NOTE 2—For soft foams having compression force deflection values less than 1.65 kPa, the pressure on the gauge or compression foot shall not exceed 200 Pa.

8.3 The scale, tape, or gauge shall be graduated so as to permit measurements within 61 % of the dimensions to be measured.

8.4 Unless otherwise specified, results shall be the mean of the measurements.

TEST A—DENSITY TEST

9. Scope

9.1 This test method covers determination of the density of uncored foam by calculation from the mass and volume of the specimen. The density value thus obtained applies only to the immediate area from which the specimen has been taken. It does not necessarily relate to the bulk density of the entire molded pad.

NOTE 3—This standard is equivalent to ISO 845.

10. Test Specimen

10.1 *Core Density*—A representative specimen of regular shape, circular or square without skins or densification lines, not less than 1000 mm³ in volume, shall be cut from a portion free of voids and defects and as near as possible to the section from which the tension and tear specimens were taken.

10.2 *Section Density*—A representative specimen with skins on the top and bottom surface measuring at least 0.1 m² in area by full-part thickness shall be cut from an area free of voids and defects and as near as possible to the location from which the tension and tear specimens were taken. When these dimensions are not possible, the largest representative portion as agreed upon between the supplier and the purchaser shall be used.

11. Number of Specimens

11.1 One specimen shall be tested, unless otherwise agreed upon by the supplier and the purchaser.

12. Procedure

12.1 Determine the mass of the specimen within 1 %.

12.2 Determine the dimensions of the specimen in accordance with Section 8, and calculate the volume.

13. Calculation

13.1 Calculate the density in kilograms per cubic metre as follows:

$$\text{Density } 5\ M/V\ 310^6 \quad (1)$$

where:

M = mass of specimen, g, and V = volume of specimen, mm³.

14. Report

14.1 Report the following information:

14.1.1 Density to the nearest 0.1 kg/m³, and

14.1.2 Type of specimen, core or section.

15. Precision and Bias

15.1 See Section 146 for Precision and Bias statements.

TEST B1—INDENTATION FORCE DEFLECTION TEST—SPECIFIED DEFLECTION (IFD)

16. Scope

16.1 This will be known as the indentation force deflection test and the results as the IFD values. This test consists of measuring the force necessary to produce designated indentations in the foam product,

Publications

GOSSELIN, G., FAGAN, MJ. 2014. Foam pads properties and their effects on posturography in participants of different weight. Accepted for publication in *Chiropractic and Manual Therapies*.

GOSSELIN, G., FAGAN, MJ. 2014. The effects of cervical muscle fatigue on balance – a study with elite amateur rugby players. *Journal of Sports Science and Medicine*. 13(2):329-37.

GOSSELIN, G., FAGAN, MJ. 2014. Effects of cervical muscle fatigue on field-dependency. Springer Plus. 3(1):78. DOI:10.1186/2193-1801-3-78.

Foam pads properties and their effects on posturography in participants of different weight

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Abstract

Background

Foam pads are increasingly used on force platforms during balance assessments in order to produce increased instability thereby permitting the measurement of enhanced posturographic parameters. A variety of foam pads providing different material properties have thus been used, although it is still unclear which characteristics produce the most effective and reliable tests. Furthermore, the effects of participant bodyweight on the performance of the foam pads and outcome of the test are unknown. This project investigated how different foam samples affected postural sway velocity in participants of different weights.

Method

Four foam types were tested according to a modified American Society for Testing and Materials standard method for testing flexible cellular materials. Thirty-six healthy male factory workers divided into three groups according to body mass were tested three times for each of the 13 randomly-selected experimental situations for changes in postural sway velocity in this cross- over study. Descriptive and inferential statistics were used to compare the results and evaluate the difference in sway velocity between mass groups.

Results

For the materials considered here, the modulus of elasticity of the foam pads when compressed by 25% of their original heights was inversely proportional to their density. The largest changes in postural sway velocity were measured when the pads of highest stiffness were used, with memory foam pads being the least likely to produce significant changes.

Conclusions

The type of foam pads used in posturography is indeed important. Our study shows that the samples with a higher modulus of elasticity produced the largest change in

postural sway velocity during quiet stance. The results suggest that foam pads used for static computerised posturography should

1) possess a higher modulus of elasticity and 2) show linear deformation properties matched to the participants' weight.

Keywords: balance, foam pads, posturography, modulus of elasticity, biomechanics.

Background

Posturography has been shown to be useful in the workplace, for example to assess different-aged workers in physically demanding jobs [1], determine the effects of obesity on balance [2], to measure sleepiness and fatigue [3], and even to observe the effects of neurotoxicity due to workers exposure to organic solvent mixtures [4]. Furthermore, there is now a trend in western countries to increase the age of retirement [5]. This aging workforce may in some instances be placed at risk should their functional capacities such as balance become altered. Approximately one person in three over the age of 65 has at least one fall a year and one person in five who falls after the age of 65 for reasons connected with balance dies in the year following the fall [6]. In addition obese adults fall nearly twice as often as their non-obese counterparts [7]. All this motivates researchers and clinicians to develop new ways to understand and quantify postural stability.

Postural stability is often assessed by measuring the centre of pressure (COP) which is a point where the vertical reaction forces of the ground act. It represents the weighted average of all pressures over the body in contact with the ground. As such, there are numerous COP measures such as average velocity of COP, COP excursion, average radial displacement of the COP, to name a few; however until recently it was not evident which measure is optimal [8]. Mahdavi-Amiri et al have shown that during static posturography the average velocity for a given stability condition, is more repeatable (less variable) between trials from a data collection session, and more discernible between the different stability conditions [9].

Many of the modern assessments systems use dynamic posturographic devices, which are sophisticated apparatus that introduce instability along with altered visual cues [10]. Unfortunately the high costs of such systems together with their large size prevent their general use in industry. Static computerised posturography represents a low-cost alternative, although the current high variability of results limits the accuracy of the conclusions that can be drawn from such assessments [11].

Recently, foam pads have been used on force platforms in order to induce increased instability thereby decreasing the coefficient of variation (CV) to a more acceptable level [12]. The use of foam pads in posturography is thought to exagerate balance deficits by altering the reliability of somatosensory input from cutaneous mechanoreceptors on the plantar soles. Previous research looking at the effect of the surface on which posturography is performed has shown that the type of foam has different effects on balance [11, 13]. Although it is still unclear which characteristics produce the optimal performance, De Berardino and colleagues suggested that using foam pads of higher stiffness was best for clinical use [11]. More specific information is therefore essential before a standardised protocol can be proposed. Foam pads used in posturography will behave as any other material when placed under load, i.e. the deflection will be proportional to both the force, by a property known as the stiffness of the structure, and proportional to the property of the material itself called the modulus of elasticity [14].

Few papers have reported the material characteristics of foam pads used in posturography. Blackburn (2003) investigated the kinematic analysis of the hip and trunk during bilateral stance on firm foam and multiaxial support surfaces. In this instance the height of the foam blocks was not mentioned but the density was reported as 54.53 kg/m^3 [15]. Another study that looked into trunk sway measurements during stance and gait tasks in Parkinson's disease [16], used foam pads with a height of 10 cm and a density of 25 kg/m^3. Finally, Di Bernardino et al [11] evaluated the postural effects of standing on two different types of rubber foam pads: a ‘‘monolayer’’ with a thickness of 10 cm and a density of 25 kg/m^3, and a ‘‘bilayer’’ pad with a thickness of 8 cm and a density of 100 kg/m^3. Their results show that the variability of static posturography parameters was significantly reduced by the use of both foam pads. However, the comparison of the two types was also statistically significant, with the bilayer type presenting the lowest CV in the results of 10%, compared with 14.4% for the monolayer. Unfortunately,the bi-layer foam pad described by Di Berardino is a specialist product that it is not readily available outside of Italy.

To the best of our knowledge no one has investigated the postural effects of participants of different mass and the effects of plantar surface area on different types of foam. One would assume that the postural effects of standing on a specific foam pad sample would be different for lighter and heavier participants. Thus, this study's main purpose was to determine how a range of foam pads (including bi-layer foam pad combinations) influenced postural sway velocity during quiet stance for subjects of different body mass. The null hypothesis tested was: there is no difference in sway velocity when any of the foam pads are used.

Method

Foam pads material properties

The properties of the pads were measured using three tests based on ASTM test D-3574-11 [17]. Uniaxial compression was achieved using a screw driven test machine (LR 100K, Lloyds Instrument, Bognor Regis, UK) with a 100 kN load cell. The press was remotely controlled via a desktop computer running Nexygen software (Lloyds Instrument, Bognor Regis, UK). Four foam pads were obtained from three sources: 1) rehabilitation material supplier, 2) online foam shop and 3) upholstery high street shop (Table 1). The pads had a size of 480×480mm, with the exception of the rehabilitation balance pad

which had a smaller size of 440×400mm. The atmospheric pressure in the laboratory was 1015 hPa and the temperature was 22^0C.

Test A: Density test

The density of the uncored foam was calculated from the mass and volume of each specimen. The pad's dimensions (m^3) were measured with the use of a millimetric measuring tape. The mean mass (kg) was recorded as the average of five measurements with an electronic scale (± 1g) (Model 1089 BKWHDR, Salter, Hamburg). The density was calculated by the formula:

Density = M / V

where: M = mass of specimen, kg, and V = volume of specimen, m^3

Test B: Indentation force deflection test (IFD)

Based on ASTM standard D-3574-11, this test consisted of measuring the force necessary to produce a predefined indentation in the foam. A flat circular indenter with a 203 mm diameter foot was used to apply a load on the specimen which was supported on a level horizontal plate that was perforated with approximately 6.5 mm holes on approximately 20mm centres to allow for rapid escape of air during the tests. From the data obtained, the modulus of elasticity was calculated for each specimen with the following formula:

$$E = \frac{\sigma}{\varepsilon} = \frac{\frac{F}{A_0}}{\frac{\Delta L}{L_0}} \quad \text{N/m}^2$$

where:

E is the Young's modulus (modulus of elasticity)

σ is the stress applied on the pad

ε is the strain measured from the application of σ

F is the force exerted on the foam pad

A_0 is the original cross-sectional area of the indenter through which the force is applied;

ΔL is the amount by which the height of the pad changes;

L_0 is the original height of the pad.

Procedure

The specimen was placed such that the indenter was in the centre of the apparatus' supporting plate. The area to be tested was preflexed twice by lowering the indenter's foot to a total deflection of 75% of the full part thickness at a rate of 250 ± 25mm/min. The specimen was allowed to rest 6

± 1 min after the preflex. The indenter was then brought into contact with the specimen by applying a 4.5 N load to the indenter's foot. The specimen was further indented at a rate of 50±5 mm/min to a displacement equal to 25% of the original thickness. The force was then adjusted to retain this displacement for 60±3s at which point the force measurement was taken. Without unloading the specimen, the deflection was increased to 65% deflection and once more the force was adjusted to retain this displacement for 60±3s when the force was recorded..

Test C: Modified indentation residual gage length test – specified force (MIRGL)

The traditional "indentation residual gage length" test force (IRGL) used to measure the thickness of the pad under a fixed force of 110N and 220N on a 203 mm diameter circular indenter foot [17]. However, these loads were not sufficient to represent the force of an adult standing on the foam pads. For this reason, the ASTM method was modified to use fixed loads of 110N, 220N 330N, 440N, 550N, 660N, 770N, 880N, 990N, 1100N, 1210N and

1320N. Furthermore, we tested the materials with two indenter sizes: 203 mm diameter and 406 mm diameter.

Procedure

The specimen was preflexed twice with a 330N force applied at 200±20 mm/min and then allowed to rest after load removal 180 ± 5 sec. Foam pads were tested either as single layer pads (MF: memory foam; Uph: upholstery foam; BP: balance pad) or a combination of two different size bi-layer pads. The first one being a large bi-layer of 0. 25m^2 surface board (MFL: Memory foam large; UphL: Upholstery foam large; BPL: balance pad large) or with a small bi-layer of 0.09 m^2 surface board (MFS: Memory foam small; UphS: Upholstery foam small; BPS: balance pad small). The deflection was then recorded after the application of 110N applied for 60 ± 3 sec. The load was then increased up to 1320N in steps of 110N, again holding for 60 ± 3 sec at each load increment. The procedures were repeated a second time with a 406 cm diameter indenter.

Posturography

Thirty-six healthy male factory workers (mean age = 39.7 years ± 9.3; mass = 88.4kg ± 14.1; height = 1.78m ± .034; BMI = 28 ± 3.1) volunteered to participate in this cross-over study. All participants were physically active and none had neurological, vestibular, visual or musculoskeletal complaints at the time of the experimentation. The participants were divided into three groups according to mass (Group 1: less than 60kg, n=5; Group 2: 60.1kg to 89.9kg, n=23; Group 3: greater than 90kg, n=8). Ethical approval was obtained for the posturography assessment from the University's Ethics committee and the procedures followed were in accordance with the ethical standards of the Helsinki Declaration of 1975, as revised in 2013 [18]. All participants read the information sheet and signed the consent form.

Postural sway velocity was recorded with the use of a force platform (QPS-200, Midot Medical Technology) linked via a USB connector to a laptop computer and the signal processed with Posture Analyser software (Midot Medical Technology). Postural sway velocities provided by the Posture Analyser software were saved in separate files on a computer.

Procedure

Posturography was measured three times for each of the 13 randomly-selected experimental situations (no foam, four samples of mono-layered foam, and eight samples of bi-layered foam). The order of each test was determined by a random sequence generator (http://www.random.org/sequences/). The bi-layered form consisted of the foam pad covered by either a square $0.25m^2$ or $0.09\ m^2$ wooden 2cm thick board. The values of the three posturographic records were averaged and used for analysis.

Participants were instructed to stand on the force platform with their feet together and eyes closed. Recording was started after 30 seconds of quiet stance. After recording was completed, participants were allowed to step offthe platform and relax for one minute before the procedure was repeated two additional times. Once the three posturographic recordings were completed, the participants were asked to stand off the force platform and the experimenter changed the foam sample according to the pre-determined sequence. Posturography was again recorded. Sampling was recorded for 30 seconds [19] at 30Hz per channel.

Analysis

The overall posturographic data and the participants' posturographic data grouped by mass were both tested for normality using the Shapiro-Wilk test. Descriptive statistics presented the mean sway velocity ($\bar{x}$), Interquartile range, 95% Confidence Interval for $\bar{x}$ and sway velocity per mass category. Statistical tests were used to determine change in postural sway velocity. One-way repeated measures analyses of variance (ANOVA) with Greenhouse-Geisser corrections were used to compare postural sway velocity in the 13 experimental situations between 1) balance without foam surfaces and 2) with 12 other foam combinations. Wilcoxon-signed rank tests were used to evaluate the difference in sway velocity between mass groups. Levels of significance were set at 0.05 and the Bonferroni post-hoc test was used in the ANOVA and Wilcoxon-signed rank tests. Statistical analyses were performed using SPSS 17.0.

Results

The density of the tested samples varied from 63.5 kg/m^3 for the Vitafoam memory foam down to 38.6 kg/m^3 for the Airex balance pad. Conversely, the memory pads had a value of E of 16.1 kPa whilst the balance pad's E was

217.9 kPa (Table 1) when compressed by 25% of their original height.

The indentation force deflection test showed that memory foam pads necessitated much lower loads in order to produce a deflection of 25 and 65% of their original height. Conversely, pads with a larger E required a larger force in order to achieve the same deflection as seen in Table 2.

The deformations of the foam pads during the MIRGL test using the 203mm indenter were non-linear with the exception of the balance pad which showed linearity throughout the range of loads applied (Figure 2). Furthermore, both memory foam and upholstery pads were compressed to more than 75% of their original length when a load corresponding to an average male's weight of 770N was used (Figure 2). The 406cm indenter did not alter the memory foam's linearity during the MIRGL test, in contrast to the upholstery pad which showed a linear deformation from 660N compression onwards with this larger indenter (Figure 3).

Posturography

The Shapiro-Wilk normality tests for changes in postural sway velocity in all participants suggested that normality was a reasonable assumption ($p>0.05$). On the other hand, when participants' results were stratified by body mass, the velocity data was not normally distributed ($p<0.05$). The average velocity, coefficient of variation, Interquartile range and average sway velocity according to body mass results according to each foam sample and indenter size are presented in Table 3.

A repeated measures ANOVA with a Greenhouse-Geisser correction determined that postural sway velocity differed significantly between surfaces measured (F(1.984, 22.257) = 21926.764, P < 0.0001). Post hoc tests using the Bonferroni correction revealed that postural sway velocity was significantly increased especially when standing on a monolayer upholstery foam and on a monolayer balance pad (75.6 ±.18.7 mm/s and 78.7 ± 13.5 mm/s respectively) (Table 4).

Wilcoxon signed-rank tests with Bonferroni corrections showed that in three experimental situations, the postural sway velocities were significantly different in participants of different masses (<60kg vs 60-89kg, upholstery foam, Z=-6.156, p=.009; 60kg vs >90kg, upholstery foam, Z=-1.950, p=.012;

<60kg vs 60-89kg, upholstery foam and large board, Z=-2.646, p=.010; 60-89kg vs >90kg, upholstery foam and large board, Z=-2.521, p=.012).

Discussion

The objective of this project was to determine which type of foam pads were the most effective to enhance postural disturbances according to participant's weight.

Foam pads

Balance during quiet stance has been shown to be a good representation of overall system health, but not a good measure of underlying pathophysiology due to numerous contributing factors potentially affecting balance. Static posturography can be altered in different ways in order to challenge the participants to maintain a stable posture for example, narrowing the base of support by having the feet close to each other, decreasing visual feedback (closing eyes), altering the standing surface to decrease proprioceptive feedback, or introducing an accessory task or action during balance recording [20]. An increased average centre of pressure change has been associated with aging, obesity, neuropathy, Parkinson's disease, vestibular loss, stroke etc. [7, 21-23]. . The usefulness in using foam pads to decrease cutaneous plantar proprioception during posturographic measurement is fairly well established [11, 24-26]. However, the types of foam pads used in previous experimentation has differed and it is difficult to compare results between studies. Through compression testing of different types of open cell foams using ASTM standard D-3574-95, our study has shown that stiffness varies as the material specimen cross-section changes in size relative to the indenter. We have demonstrated that foams pads, with the exception of the balance pad and the upholstery foam with the 406mm indenter, did not show linear deformation throughout the range of loads used in the MIRGL with both the 203mm and 406mm indenters. Both memory foam pads failed to resist the compression at relatively low loads which suggested they would not provide sufficient resistance to compression during posturography for healthy adult participants. Their compression slopes during the MIRGL clearly show a trend towards asymptotic displacement beyond 220N for the memory foam and beyond 660N compression for the mono-layer upholstery foam. Non-linear stress-strain relationships were observed due to the changes in the foam geometry at high strains. When the foam is highly compressed the foam volume tends to zero and the stiffness tends to infinity. Patel suggested that such large compression (as observed with the memory foam here) would result in the participants coming in to close contract with the rigid surface beneath the foam [13]. The balance pad showed a largely linear response throughout the loads applied during the MIRGL test. Conversely, the upholstery foam exhibited a bi-linear type of behaviour when compressed with the 406mm diameter indenter. It supported the load with minimum deformation up to 660N, at which point it gave way and deformed with a lower stiffness up to the maximum load.

Our results show that foam pads can indeed increase the postural sway velocity of healthy participants, in some cases significantly. Participants standing on foam pads did elevate their centre of mass by nearly 50mm corresponding to less than 3% of the participants' average height. The force platform used in this project consisted of 4 weighing plates, and the CoP is calculated from the resultant force, with the velocity calculated by the change in the CoP position. It is therefore unlikely that elevating the centre of mass would have affected appreciably the postural sway velocity results. When participant data were stratified according to mass, results showed that the balance pad did still produce the largest increase in sway velocity in Groups 1 and 2, in the heavier Group 3 (mass > 90kg), the large bi-layer upholstery foam pad had the largest effect. The pairwise comparison between sway velocities without foam and with foam surfaces showed a large confidence interval, which can be attributed to the separation of participants into smaller groups according to mass. The null hypothesis stating "there is no difference in sway velocity when any of the foam pads are used" can thus be rejected. Furthermore, our participants were male factory workers with a mean BMI of

28 which is slightly higher than the UK male average [27]. Athletes presenting the same mass but with a more mesomorphic body type might have provided different results.

It is interesting to note that not only was there no significant difference between posturographic results between "no foam" and samples of 75mm and 100mm thick memory foam samples, but the sway velocity was somewhat improved when memory foam pad were used. A learning effect explanation can be excluded in view of the random order of the test conducted. We concluded that because the participants' feet had a smaller cross-sectional area than the pads onto which they were standing on and the fact that our participants nearly flattened the pads meant a shear force was created between the material and the sides of the feet as the specimen deformed. This would have increased the surface area of contact between the foam pads and the side of the feet which in turn would most likely have increased proprioception thereby providing additional cues and improving balance. With participants of larger mass, as the deflection increased, the memory foam could actually have provided an advantage in the posturographic task. Thus, when selecting a type of foam pad to be used in posturography, it is recommended that investigators select samples appropriate to their participants' weight. For instance, in the selection of foam pads for individuals weighting more than 900N, a bi-layer upholstery foam pad of around 37.3kPa and 44.9 kPa such as used in our experiment would be the appropriate choice. Additionally, it may be of importance to select a foam pad presenting limited deflection under loading in order to avoid contact of the feet with the sides of the material.

Conclusion

The Balance pad produced the largest postural sway velocity in participants with less than 90 kg mass whilst the bi-layer upholstery sample (406mm indenter) produced the largest changes in participants above 90 kg of mass. The results suggest that foam pads selected for static computerised posturography: 1) could possess a modulus of elasticity of around 40kg/m^3,

and 2) show linear deformation properties matched to the participants' weight.

Competing interests

The authors confirm that they have no financial or non-financial competing interests.

Authors contributions

GG designed, executed and analysed the entire experiment and prepared the manuscript. MF assisted in design and testing materials. Both authors read and approved the final manuscript.

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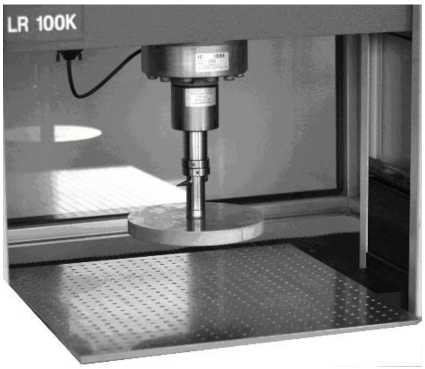

Figure 1. Screw driven test machine (LR 100K, Lloyds Instrument, Bognor Regis, UK) with a 100 kN load cell showing the 203cm indenter foot above the perforated horizontal support plate.

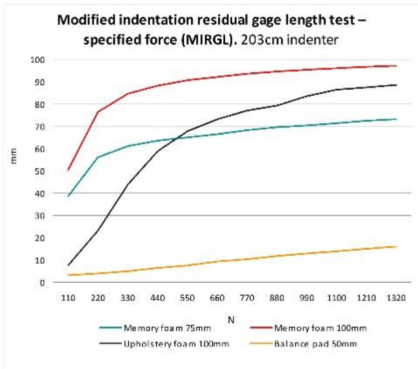

Figure 2 Results from the modified indentation residual length test using the 203mm indenter foot.

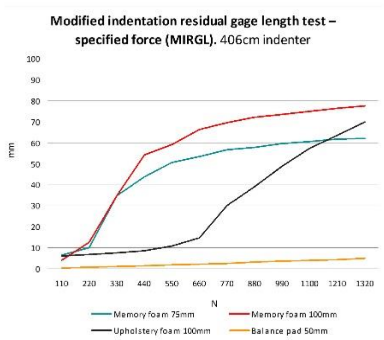

Figure 3 Results from the modified indentation residual length test using the 406mm indenter foot

Table 1. Foam sample specification

Manufacturer	Model	Type	Size (mm)	Volume (m^3)	Mass (kg)	Density kg/m^3	*E* kPa
Vitafoam Ltd UK	Memory Foam Vasco 40 MF-75mm	Urethane Open-Cell	480 x 480 x 75	0.01728	1.07	63.5	16.1
Vitafoam Ltd UK	Memory Foam Vasco 40 MF-100mm	Urethane Open-Cell	480 x 480 x 100	0.02304	1.46	63.5	16.1
Vitafoam Ltd UK	Reflex 35 M Ups-100mm	Urethane Open-Cell	480 x 480 x 100	0.02304	0.86	37.3	44.9
Airex AG Speciality Foams Industrie, Switzerland	Balance Pads BP-50mm	Polyurethane Closed-cell	440 x 400 x 50	0.0088	0.34	38.6	217.9

The density was calculated by dividing the mass by the volume. *E* was measured using the data provided by the indentation force deflection test when the specimen was compressed by 25% of its original height.

Table 2. Indentation force deflection test (IFD)

	203cm diameter indenter	
	Load (N) at 25% thickness	Load (N) at 65% thickness
MF-75mm	65.2	169.5
MF-100mm	74.7	200.6
Uph-100mm	181.3	550.7
BP-50mm	880.9	4861.2

Table 3 Descriptive statistics of overall posturographic and participants' results stratified by body mass.

	$\bar{x}$ (SE) mm/s	IQR	95% CI for $\bar{x}$		<60kg		60-89kg		>90 kg	
					$\bar{x}$	Mdn	$\bar{x}$	Mdn	$\bar{x}$	Mdn
No foam	25.1 (1.98)	18.7	21.1	27.7	29.1	21	24.0	28.5	24	28.5
MF-75mm	23.4 (1.83)	15.5	19.7	22.6	27.1	18	22.3	27.1	21	25.5
MF-100mm	22.3 (1.88)	14.7	18.4	21.4	26.1	17	21.2	25.8	20	24.5
Uph-100mm	75.6 (3.1)	23.2	69.2	85.7	**81.9**	82	82.1	49.5	45	49.5
BP-50mm	78.7 (2.2)	23.7	74.1	82.7	**83.2**	79	**82.0**	66.5	62	66.5
MFL-75mm	27.0 (1.9)	18.3	23.1	27.7	30.9	24	26.1	28.8	24.3	28.8
MFL-100mm	32.8 (2.0)	18.7	28.8	29.7	36.8	36	31.4	30.5	26	30.5
UphL-100mm	64.5 (2.6)	24.5	59.3	67.7	69.7	64	57.0	81.4	**76**	81.4
BPL-50Lmm	33.0 (1.9)	19.75	29.2	33.7	36.9	30	33.0	32.5	28	32.5
MFS-75mm	25.5 (2.0)	19.1	21.4	26.8	29.6	21.4	24.4	28.7	24.1	28.6
MFS-100mm	29.0 (2.2)	18.5	24.5	42.7	33.4	39	24.6	28.6	23.5	28.0
UphS-100mm	48.4 (2.4)	20.5	43.6	44.7	53.3	41	44.0	63.5	59	63.5
BPS-50mm	34.0 (1.9)	19.8	30.0	34.7	38.1	31	34.0	33.5	29	33.5

$\bar{x}$ (SE) = average velocity and its standard error. IQR = Interquartile range. CI – 95% confidence interval for the average velocity of sway.
MF: memory foam; Uph: upholstery foam; BP: balance pad; Large bi-layer with a surface of 0. 25m^2 board: MFL: Memory foam large; UphL: Upholstery foam large; BPL: balance pad large; Small bi-layer with a surface of 0.09 m^2 : MFS: Memory foam small; UphS: Upholstery foam small; BPS: balance pad small.

Table 4 ANOVA Pairwise comparison between velocity of sway without foam and with different foam surfaces

		p	95% CI for Difference with No Foam	
Mono-layer	MF-75mm	ns	-0.3	3.7
	MF-100mm	.002	0.6	5.0
	Uph-100mm	.000	-61.0	-39.9
	BP-50mm	.000	-58.8	-48.2
Bi-layer 0.09m^2	MFL-75mm	.030	-3.6	-0.08
	MFL-100mm	ns	-15.1	-0.2
	UphL-100mm	.000	-44.5	-34.1
	BPL-50Lmm	.000	-9.2	-6.5
Bi-layer 0.25m^2	MFS-75mm	ns	-2.2	0.8
	MFS-100mm	ns	-8.4	0.6
	UphS-100mm	.000	-27.2	-19.3
	BPS-50mm	.000	-10.2	-7.5

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Research article

The Effects of Cervical Muscle Fatigue on Balance – A Study with Elite Amateur Rugby League Players

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Abstract

Neck muscle fatigue has been shown to alter an individual's balance in a similar way to that reported in subjects suffering from neck pain or subjects that have suffered a neck injury. The main purpose of the present study was to quantify the effects of neck fatigue on neck muscle electromyography (EMG) activity, balance, perceived fatigue and perceived stability. Forty four elite amateur rugby league players resisted with their neck muscles approximately 35% maximum voluntary isometric contraction (MVIC) force for 15 minutes in eight different directions. Sway velocity and surface electromyography were measured. Questionnaires were used to record perceived effort and stability. Repeated measures ANOVA showed that after 15 minutes isometric contraction, significant changes were seen in sway velocity, perceived sway and EMG median frequency. There were no differences in perceived efforts. The changes in sway velocity and median frequency were more pronounced after extension and right and left posterior oblique contractions but there was no significant difference in sway velocity after contraction in the right lateral flexion, right anterior oblique and left anterior oblique direction of contraction. All the subjects showed oriented whole-body leaning in the plane of the contraction. The experiment produced significantly altered and perceived altered balance in this group of physically fit individuals. The results may contribute to our understanding of normal functional capacities of athletes and will provide a basis for further investigation in healthy non-athletes and participants that have suffered neck injuries. This may ultimately help develop accurate and valid rehabilitation outcome measures.

Key words: Biomechanics, posturography, neck pain, EMG, sports.

Introduction

Neck injuries account for a significant portion of accidents and compensation in the general population. The incidence of such injuries is coincidently quite high in both rugby league and rugby union players. It has been reported that in rugby union, the majority of injuries appear to be the result of buckling of the cervical spine (Kuster et al., 2012). Unfortunately, very little is known about the exact mechanism of injury and the resultant functional disturbances experienced by players (King et al., 2011). Even though our understanding of the relationship between neck injury, neck pain and muscle fatigue is improving, clinically practical methods of assessment disability due to injuries to the cervical spine are few in number (MacDermid et al., 2009, Humphreys, 2008).

Researchers have reported long lasting altered balance due to cervical extensor muscle fatigue (Gosselin et al., 2004, Schieppati et al., 2003, Stapley et al., 2006, Duclos et al., 2004) or after participants were subjected to cervical mechanical stress (Field et al., 2008, Gosselin and Blouin, 2000). Duclos (2004) showed the effects to be present after 30 seconds of either lateral flexion or posterior oblique isometric contraction. No information to date is available on the postural effects of neck flexion or anterior oblique isometric contraction.

The main cause of altered balance following neck muscle isometric contraction appears to be proprioceptive conflicts and possibly central fatigue which in turn increases the sway velocity during quiet stance (Gandevia, 2001, Gosselin et al., 2004). Afferences from small sized muscles have been shown to be modified by central fatigue (Pettorossi et al., 1999). The density of muscle spindles is higher in the small intrinsic, deep dorsal and sub-occipital cervical muscles than in other cervical muscle groups which accounts for their important role in proprioception (Peck et al., 1984, Rix and Bagust, 2001). Djupsjöbacka et al. (1995) therefore suggested that fatigue of sub-occipital muscles could alter balance due to the activation of tonic gamma motor neurons in response to a build-up of muscle contraction metabolites. The consequence of such an accumulation (of K^+, arachidonic and lactic acids) is the promotion of group III and IV afferent signals, leading to positive feedback and further excitation of muscle spindles and gamma motor system hyperactivity (Knutson, 2000; Thunberg et al., 2001). At this point it is unknown if altered function of other cervical muscle groups will influence balance.

Surface electromyography (SEMG) has been used extensively to study muscle fatigue. If muscle contractions are maintained over a certain period, the SEMG power density spectrum shifts towards the lower frequencies, with the change in SEMG being proportional to the build-up of H^+ in the muscle as metabolites are produced and broken down (Oddsson et al., 1997). The median frequency, as measured by SEMG during muscle contraction, is therefore a good indicator of muscle fatigue as it is directly proportional to the build-up of muscle metabolites during a prolonged voluntary muscle contraction (Merletti et al., 1992, Solomonow et al., 1990, González-Izal et al., 2010, Beck et al., 2013).

Increased postural sway is a common symptom of neck trauma as seen in rugby injuries and it is generally attributed to injury involving peripheral and/ or central components of the cervical somatosensory and/or vestibular system (Treleaven et al., 2005, Madeleine et al., 2004, Loudon et al., 1997). Although computerized static posturography is widely used to measure balance impair-

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ments, its main limitation is its high intrinsic inter-individual variability (Di Berardino et al., 2009). Investigators have attempted to decrease what is considered unacceptable static posturography variation by introducing either dynamic disturbances during quiet stance (Koozekanani et al., 1980, Cyr et al., 1988) or by changing the subject's position into a more unstable stance. Unfortunately the high costs of computerized dynamic posturography systems places this type of assessment out of the reach of most clinicians. Investigators have thus turned to measuring quiet stance with subjects standing on foam pads which is thought to amplify postural sway by decreasing the reliability of somatosensory information from cutaneous mechanoreceptors on the plantar surface (Di Berardino et al., 2009).

The purpose of the present study was thus to measure the effect of sustained isometric cervical muscle contraction in eight different directions on balance and perceived stability.

Methods

Forty four (n = 44) healthy male players from the National Conference League premiership (age = 24 ± 2 years; weight = 91± 5.5kg, height = 1.84 ± 3.2m) volunteered for inclusion in this cross-over design study. Exclusion criteria applied included cervical trauma, neck or lower limb pain and visual disturbances during the last three months. Ethical approval was obtained from University's Ethics Committee, and all participants read the information sheet and signed a consent form. Participants were randomized into two equal groups of 22 individuals according to their surnames.

Cervical isometric contraction

Neck muscle fatigue was induced through isometric contractions (Schieppati et al., 2003, Gosselin et al., 2004). Participants were asked to stand comfortably on a predetermined target, with the feet touching each other on a force platform with their arms to their side and leaning slightly towards a support pad. This was provided to help stabilize body movement during the experiment, and was part of a custom built supporting structure (Figure 1). A head weight training harness was placed on the participant's head, from which a cable extended horizontally (standardized between participants) and was attached via a pulley system to an adjustable mass. No significant contraction of the thoracic or lumbar muscle chain below the level of the support was assumed required in order to maintain a steady stance. A marker was attached to the pulley and the experimenter observed if the pulley remained co-planar with a reference point fixed to the supporting structure. During the isometric contraction, the experimenter would give a verbal cue in order for the participant to either increase or decrease the cervical muscle force against the weight thereby maintaining a static head/neck position during 15 minutes. Eight different effort orientations were used each at 45° offset from the previous one (Figure 1). In order to decrease bias due to a participant's tiredness, the experiment was conducted over two days. On day one group 1 was tested in four randomized orthogonal positions (viz. E, F, RLF & LLF). On day two the remaining effort orientations were tested (viz. RPO, LPO, LAO & RAO). The order was reversed for Group 2.

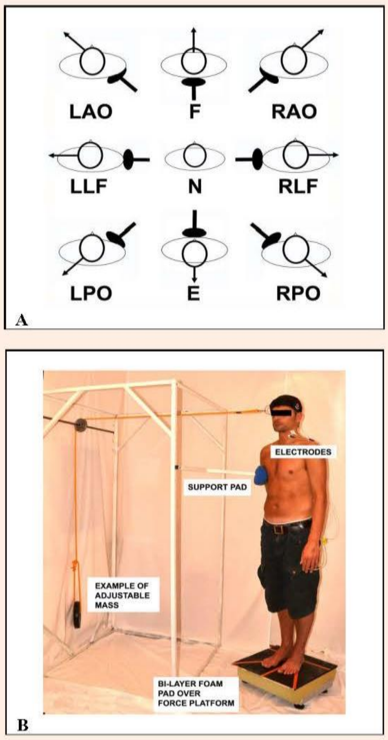

Figure 1. A. The orientation of efforts and neutral position (N). extension (E), right posterior oblique (RPO), right lateral flexion (RLF), right anterior oblique (RAO), left posterior oblique (LPO), left lateral flexion (LLF), left anterior oblique (LAO) and flexion (F). B. Experimental setup showing the subject performing an isometric contraction resisting the adjustable mass in the left posterior oblique direction (LPO). The subject is standing on a force platform covered by a bi-layer foam pad. The effort is produced against a cable placed over a pulley to an adjustable mass. The surface electrodes can be seen over the left shoulder and neck

The load set on the cable was approximated to 35% of the maximum isometric voluntary contraction (Table 1), and was calculated individually for each participant by adapting the isokinetic neck strength profile of elite rugby players data (Olivier and Du Toit, 2008). The isokinetic values were less than other reported valued but permitted us nonetheless to standardize the loads used (Geary et al., 2013). Neck length was measured from the spinous process of the vertebral prominence (C7) to the occipital notch

Table 1. Example of the average masses in kilograms used in each subject for a particular movement.

Direction	E	RPO	RLF	RAO	LPO	LLF	LAO	F
Average torque (Nm) *	56.2	59.5	59.7	50.5	59.5	58.9	50.5	38.9
Peak mass (kg)	54	57.2	57.4	48.6	57.2	56.6	48.6	37.4
35% Peak mass (kg)	18.9	20.0	20.1	17.0	20.0	19.8	17.0	13.0

The mass was obtained by dividing peak torque adapted by from Oliver and Du Toit (2008) by each subject's neck length. The mean neck length was 10.6cm. This peak force was divided once more by the gravitational constant to obtain the load used in kilograms. * Presented by Olivier and Du Toit, 2008)

at the base of the skull, while the head was held in the Frankfort plane (Olivier and Du Toit, 2008).

Due to the absence of normative data for the oblique contractions, we averaged the torque from either the extension and lateral flexion or the lateral flexion and flexion. For example, the RPO load was determined by averaging the E and RLF torques.

Electromyography

Surface electromyography was used to assess changes in muscles involved in isometric contraction. A two-channel EMG system was used to record the SEMG signal during the isometric contraction (iWorks system Model 214, Dover, USA). Standard settings were selected for the assessment, with the low pass filter set to 500Hz, the high pass filter to 10Hz, and the gain to 500 with the common mode rejection ratio set to 110dB. The inter-electrodes distance was 2 cm. Due to the difficulty in accessing specific muscles with surface electrodes, the electrode placement was location-specific rather than muscle-specific (Strimpakos et al., 2005). Electrode placements for the different directions of contraction are presented in Table 2.

The leads were linked to the skin and connected to the iWorks unit. Sampling started 15 seconds after the onset of the muscle contraction and lasted for 4.096 seconds at a rate of 2 KHz and once more after 14 minutes of isometric contraction. The real time wave form was displayed through LabScribe V2.0 software (iWorks, Dover, USA). The raw EMG was processed by performing a linear magnitude fast Fourier transform (FFT) followed by an integration and normalization of the spectrum (values from 0 to 1 volt), with normalization achieved through division by the maximum recorded value. The median frequency of the EMG spectrum was then identified at a value of 0.5. Where SEMG was recorded from two muscles, the median frequencies were averaged to produce one single result.

Posturography

Postural sway velocity and center of pressure displacement (COP) were recorded with the use of a force platform (QPS-200, Midot Med. Technology) linked via a USB connector to a laptop computer and the signal processed with Posture Analyser software (Posture Midot Medical Technology). Postural sway velocity and COP displacement plots provided by the Posture Analyser software were saved in separate files on a computer. One 10cm x 50cm x 50cm bi-layer foam pad was placed on the force platform, where the modulus of elasticity of the foam was measured to be 399N/m² (Gosselin, 2011). Participants were asked to stand on the foam pad, feet touching each other with their eyes closed and without their body touching the apparatus' padded vertical support. Sampling was recorded for 30 seconds (Prosperini et al., 2013) at 30Hz per channel on two occasions: 1) One minute before the isometric contraction was started, 2) 15 seconds after the end of the isometric contraction.

Subjective exertion perception

Participants were asked to rate their perceived fatigue/exertion using the Rating of Perceived Exertion (RPE) Borg CR-10 scale. The Borg CR-10 scale consists of a vertical scale labeled 0 to 10 with corresponding verbal expressions of progressively increasing sensation intensity (Borg, 1990).

Subjective postural stability perception

Participants were asked to rate their perceived postural stability by using the same stability scale as used by Schieppati (Schieppati et al., 2003). Scores ranged from 10 (I feel really still, as if supporting myself using a stable frame) to 0 (unable to stand without falling) (Schieppati et al., 1999, Schieppati et al., 2003).

Procedure

The EMG electrodes were applied. The participants stood in a relaxed position with their eyes closed on the foam pad with their body approximately 2 cm away from the support apparatus' padded vertical support. Posturography was measured for 30 seconds. The head weight training strap was adjusted to the head and the appropriate weight

Table 2. Surface EMG electrode placement and potential contribution of each muscle to different actions produced. (based on the method of Strimpakos et al., 2005).

Muscle group	Electrode placements	Action associated with muscles	Reference electrode
Splenius capitis (SC)	Over the muscle belly at C2/3 level between the uppermost parts of trapezius and sternocleidomastoid	RPO, RLF, RAO, LPO, LLF, LAO	C7 spinous process
Sternocleidomastoid (SCM)	Over the muscle belly, about 1/3 of the length rostral to the sternal attachment	RLF, RAO, LLF, LAO, F	Acromion

Cervical paraspinal group (CPG); trapezius, capitis and cervicis groups)	2 cm from the midline at C4 level	E, RPO, LPO,	T1 spinous process

Table 3. Paired samples tests of SEMG median frequency of the cervical muscles recorded showing mean and their standard error mean, lower and upper 95% confidence interval of the difference, t statistic (degree of freedom: 43) and significance.

Direction	Mean (Hz)	SE means (Hz)	t	95 %CI	p
E	35.5	.43	43	34.6 – 36.4	.001
RPO	33.3	.39	84.5	32.6 – 34.1	.001
RLF	60.7	.55	111.3	59.6 – 61.8	.001
RAO	60.1	.49	122.8	59.1 – 61.1	.001
LPO	32.8	.32	103.6	32.1 – 33.4	.001
LLF	28.1	.25	112.9	27.6 – 28.6	.001
LAO	27.7	.19	142.4	27.3 – 28.1	.001
F	27.6	.17	159.2	26.9 – 27.6	.001

Bonferroni correction for eight situations set significance at less than 0.0018.

was placed at the end of the cable. During the neck extension muscle sequence, the participants were instructed to lean forward sufficiently for their chest to touch the padded vertical support and thus maintain the position of the head and neck, and to readjust the position should the experimenter give them a verbal cue. SEMG signals were recorded both from the onset of the contraction and again during the last minute of contraction. These instructions were repeated for to the seven other positions. During the first minute of contraction, participants were shown a Borg CR-10 chart and were asked to select a number on the chart that corresponded to their perceived effort. The contraction was maintained for 15 minutes (Gosselin et al., 2004), during the 14th minute, participants were again shown the Borg CR-10 chart and asked to rate their perceived fatigue.

Once 15 minutes of isometric contraction were completed, the head weight training straps were immediately removed and the participant was asked to hold a comfortable standing position with their eyes closed without touching the support pad. The distance away from the support pad was not standardized. Posturography was again measured for 30 seconds. Participants were then asked to rate their subjective feelings of stability. Participants were allowed 15 minutes recuperation between experimental situations. Overall, the experimentation of the four situations lasted between 2.25 to 2.50 hours.

Statistical analyses

Statistical analyses were performed using SPSS 17.0. The data was tested for normality using the Shapiro-Wilk test. Paired t-tests measured the differences in myoelectic activity and sway velocity between the beginning and end of the isometric contraction. One-way repeated measures analysis of variance (ANOVA) with Greenhouse-Geisser corrections were used to compare myoelectric activity differences and postural sway velocity differences in all eight situations. Paired t-tests compared differences in sway velocity changes after 15 minutes of isometric contraction, RPE (Borg CR-10) and Scheppati scores for each situation individually. Levels of significance were set at 0.05. Bonferroni correction post-hoc test was performed for all t-tests and ANOVAs.

Results

The Shapiro-Wilk normality tests for EMG frequency and sway velocity suggested that normality was a reasonable assumption.

Surface electromyography

Paired t-tests with Bonferroni correction showed that the SEMG median frequency of the cervical muscles recorded during the 1st and 15th minutes of isometric contraction were significantly different in all eight situations (Table 3).

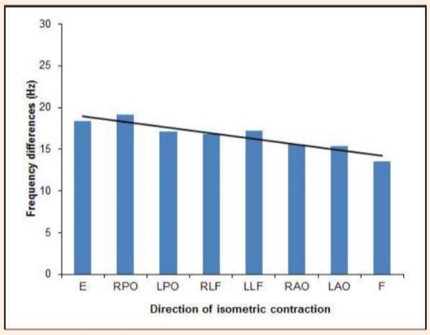

Figure 2. Mean EMG frequency differences (Hz) and standard deviations and linear trend line between initial recording during the first minute of contraction and after 14 minutes in 8 different direction of isometric contraction.

Figure 2 shows changes in median frequency between the first and the last minute of contraction, with the trend line showing that smaller changes were recorded from the anteriorly contracting muscles. A one-way repeated measures ANOVA with Greenhouse-Geisser corrections confirmed that different directions of the 15 minute isometric contractions produced significant changes in the 'before' and 'after' differences SEMG median frequency ($F(4.196, 180.436) = 136.377$, partial $\eta^2 = 0.760$, $p < 0.001$). Post hoc tests using the Bonferroni correction revealed that changes in SEMG frequency during E were significantly different to all other contractions ($p < 0.001$). There were no significant changes in before and after differences in median frequencies between the RPO, RLF and LLF. Nor were there any differences between F, LAO and RAO.

Posturography

Descriptive statistics showed the postural sway velocity to be the largest in isometric contractions involving neck extensor muscles. Changes in velocity were the least affected by the isometric contraction during F, LAO and RAO (Figure 3).

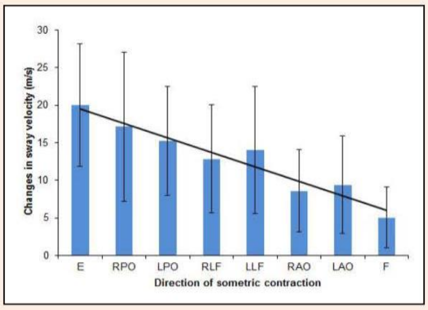

Figure 3. Mean differences in sway velocity and standard deviations and linear trend line after 14 minutes in 8 different direction of isometric contraction.

Paired t-tests with Bonferroni correction showed that the postural sway velocity recorded after the 15 minutes isometric contraction produced a significant increase in velocity in E, RPO, and LPO (Table 4).

A one-way repeated measures ANOVA with Greenhouse-Geisser correction showed that significant differences were present between the different effort orientations for postural sway velocity changes ($F(5.77, 248.103) = 25.599$, partial $\eta^2 = 0.373$, $p < 0.001$). Post hoc tests using the Bonferroni correction revealed that postural sway velocity changes were present predominantly in the sagittal plane of contraction. Mirror contractions in the transverse plane did not show significant differences in sway velocity. LPO vs. RPO, LLF vs. RLF, and LAO vs. RAO where all insignificant, whilst all other interactions were significantly different ($p < 0.01$).

Centre of Pressure (COP)

After 15 minutes of muscle contraction, all the participants showed oriented whole-body leaning in the plane of the contraction, which lasted so long that the participant had to compensate repeatedly for this disequilibrium. Figure 4 shows observed COP in neutral position compared to the observed COP motor post-effects that are oriented in the same plane of contraction. Nevertheless, the spatial characteristics of the postural post-effects varied according to the cervical muscle group previously contracted. While postural post-effects were oriented in one direction, the positive or negative value differed in each participant. For example, all participants increased COP displacement in the sagittal plane after contraction, but as seen in previous studies, half of the participants moved forward and half moved backwards. This was observed again in this study, but to a lesser extent during lateral and anterior oblique contractions.

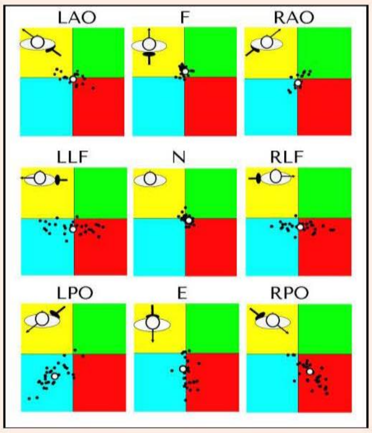

Figure 4. Centre of pressure (COP) motor post-effects (leaning) are seen oriented in the same direction of contraction after 15 minutes isometric contraction. Extension (E), right posterior oblique (RPO), right lateral flexion (RLF), right anterior oblique (RAO), left posterior oblique (LPO), left lateral flexion (LLF), left anterior oblique (LAO), and flexion (F). White circle represents average change in COP.

Subjective perception of effort and balance

A one-way repeated measures ANOVA with Greenhouse-Geisser corrections showed that participants' perception of stability was changed after 15 minutes neck muscle isometric contractions in different directions ($F(1.155, 49.564) = 274.03$, $p < 0.001$; Wilks $\lambda = 0.011$, partial $\eta^2 = 0.989$). Post hoc tests using the Bonferroni correction showed that the participants' perceived decrease in stability after isometric contraction occurred mostly during

Table 4. Paired samples tests of postural sway velocity showing mean and their standard error mean, lower and upper 95% confidence interval of the difference, t statistic (degree of freedom: 43) and significance.

Direction	Mean (mm/s)	SE mean (mm/s)	t	95 %CI	p
E	10.2	1.6	6.3	6.9 – 13.5	.001
RPO	7.4	1.9	3.9	3.5 – 11.1	.001
RLF	3.1	1.6	1.9	.1 – 6.2	.058
RAO	-1.2	1.4	.842	-4.0 – 1.65	.404
LPO	5.5	1.5	3.6	2.4 – 8.5	.001

LLF	4.3	1.8	2.4	.7 – 7.8	.061
LAO	-.39	1.4	.268	-3.3 – 2.5	.790
F	-4.7	1.0	-4.6	-6.8 - -2.7	.001

Bonferroni correction for eight situations set significance at less than 0.0018.

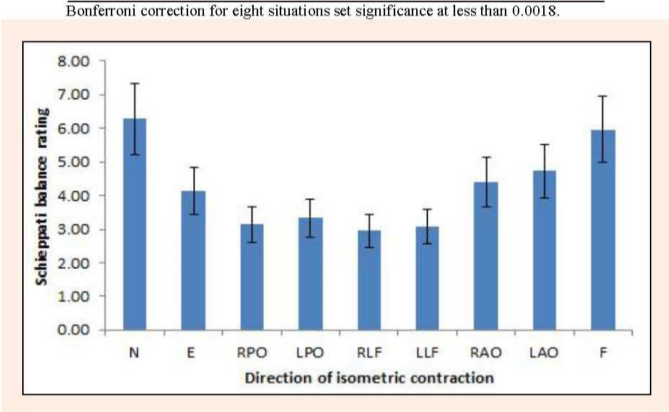

Figure 5. Pre and post isometric contraction perceived sway. The perceived sway and standard deviation between normal stance feet together/eyes closed (N) and after 15 minutes isometric contractions in eight different positions. Feeling of decreased stability is represented by a lower score.

contractions involving some lateral movement (Figure 5). Perception of effort (RPE) on the other hand was not significantly different between directions of contraction (Figure 6).

Discussion

The results of the present study showed that 15 minutes isometric contraction of various neck muscle groups at approximately 35% MVIC produced a significant change in the EMG median frequency in all positions and changed significantly the sway velocity in all directions except F, RLF, RAO, LLF and LAO.

Muscle fatigue

Fatigue development protocols in previous studies have either asked participants to resist loads of 25% or less MVIC from 5 to 15 min, to 35% MVIC for 5 minutes (Schieppati et al., 2003, Edmondston et al., 2011, Stapley et al., 2006, Gosselin et al., 2004). However, a preliminary study showed that this level of activity was not sufficient to produce significant fatigue or a significant change in the EMG median frequencies in the present participants. It was assumed that this was due to the increased neck muscle strength found in healthy and fit elite amateur rugby league players compared to healthy non-athlete males (Gage et al., 2004, Hogrel et al., 2007). We therefore adapted our protocol by raising the isometric contraction resisted load to 35% of MVIC as used by Stapley et al. (2006) and Schieppati et al. (1999) and extending the contraction period to 15 minutes. Our results confirm that this increased resistance torque produced the required signs of muscle fatigue as manifested by the significant EMG median frequency shift to lower frequencies over the course of the contraction. This shift was more prominent in muscles producing posterior movements such as E, RPO and LPO, which is interesting in view of the fact that all muscles contracted for the same amount of time

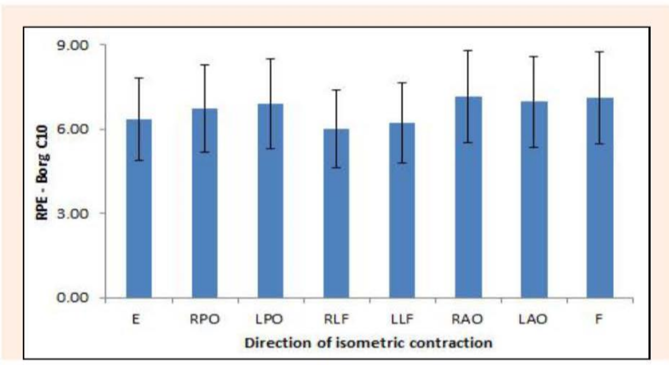

Figure 6. Pre and post isometric contraction perceived exertion. The perceived exertion and standard deviation after 15 minutes isometric contractions in eight difference positions. Feeling of more intense effort is represented by a higher score.

and at the same percentage of MVIC. This observation is unlikely to be explained our population of highly trained athletes. This could be explained by the difference in proprioceptive receptors in extensor and flexor muscles. The extensor muscles have a higher density, different distribution and morphology of muscle spindles in posterior sub-occipital muscle such as the superior oblique capitis, inferior oblique capitis and rectus capitis posterior major and minor sub-occipital muscles (Kulkarni et al., 2001). These muscles contain up to 100 times more muscle spindles than a muscle such as the trapezius which is one of the main cervical extensor muscle and this may explain their susceptibility to fatigue and hence their greater post-effect loss of proprioceptive function when fatigued (Boyd-Clark et al., 2002).

Postural sway velocity

Mean postural sway velocity appears to be the parameter which shows the least variability and provided the most reliable estimate of COP displacement (Lin et al., 2008, Hadian et al., 2008). COP displacement was therefore selected as the balance parameter for this study.

As shown in previous studies, fatigue of postural muscles such as cervical, lumbar and lower limb extensor muscles reduces the efficiency of postural mechanisms to a greater extent than non-postural muscles (Lin et al., 2009). In our study, postural sway velocity increased after neck extensor muscle contraction which confirms that contraction duration and resistance were set correctly. In addition, the data presented in Figure 3 shows a clear trend. Larger changes in postural sway velocity were observed when posterior muscle groups were fatigued (E; RPO; LPO). Whereas smaller changes in postural sway velocity were observed when anterior muscles were fatigued (F; RAO; LAO). These patterns of sway velocity changes correspond to changes in EMG frequencies. Martin (2006) has shown that in upper arms during fatigue inputs from group III and IV muscle afferents from homonymous or antagonist muscles depress extensor motoneurons where as motoneurons innervating flexors are facilitated (Martin et al., 2006). It is presently unknown if these findings can are applicable to neck muscles. It is possible that neck muscle fatigue or other flexor muscle groups co-activating during the muscle contraction could have affected the sway velocity, as repetitive contraction during a fatigue protocol have been shown to alter postural characteristics (Tarantola et al., 1997, Choi, 2003). This could have produced a Type 1 error. Furthermore, changes in postural parameters sometimes occur after changes in the participants' position therefore any changes in the COP could may have indirectly induced altered velocities (Schieppati et al., 1994). However this was unlikely to occur in our study as the participants' feet and distance from the support pad were controlled for in all conditions.

Posturography also provided information on the participants' COP post-effect displacement in the plane of contraction. "Postural post-effects" are increased body leaning associated to a change in postural reference resulting from a proprioceptive inflow as seen after fatiguing neck muscles. An increase in postural post-effect displacement, mainly in the sagittal plane, has been reported during short duration contraction of postural muscles (Duclos et al., 2004). In a further study, Duclos supported the hypothesis that the change in the postural reference was caused by the erroneous proprioceptive message produced by a sustained voluntary muscle contraction (Duclos et al., 2009). On the other hand Duclos' method differed significantly as he reported on the post-effects of just 30 second contractions and the fatigue protocol had participants sitting instead of standing. . It has also been suggested that the effects observed in this study could be due to changes in the internal representation of the upper body following signs of muscle fatigue (Takahashi et al., 2006).

Perceived effort and perceived postural sway

There were variations between the ratings of perceived exertion although the differences were not significant. We attribute this situation to the methodology used whereby loads were calculated as a percentage of the respective muscle's MVIC. Absence of change in perceived effort has also been reported in a study on military helicopter flight crews (Harrison et al., 2009). Pilots were asked to perform 70% MVIC efforts for a maximum of 180 seconds in flexion, extension and right and left lateral flexion. No statistically significant differences were found between RPE for the four isometric contraction trials ($p = 0.81$). The lack of change in perceived effort is unusual in non-elite athletes as there is a wide variation in perceived subjective muscle fatigue in the general population (Dedering et al., 1999, Troiano et al., 2008, Veldhuizen et al., 2003). This finding could be explained by our sample of participants who were highly trained elite athletes, including three that had played previously in the Super League as professionals. Furthermore, the Borg CR-10 scale results showed that after 15 minutes contraction the perceived effort was scored at less than seven for nearly all participants which indicated that the effort produced, although perceived as difficult, was relatively well tolerated by most. Nonetheless, increased perceived postural sway was more pronounced after posterior and laterally oriented isometric contractions than after contraction of the anterior group of muscles. This perceived instability corresponded correlated with sway velocity measurements but did not correlate with perceived effort or changes in EMG frequency. If we assume that central factors controlling muscle contraction are equal for the various muscle groups used in this study, differences in postural stability and EMG signal must be attributed to local muscular mechanisms.

Rugby union neck injury incidence occur mostly in the scrum, tackle and rucks and mauls and can be nearly 10 per 1000 player hours for mixed populations although there is still a scarcity of severity and analytical data (Swain et al., 2011). Rugby league incidence of neck and spinal injuries is different as most of the injuries occur during tackle and occur in 2.9 per 100,000 players (King et al., 2011). The long-term significance of these injuries can be seen in many of these players who may show evidence of early degenerative changes from as early as 21 years of age (Castinel et al., 2010). In addition to structural changes, players can also show persistent functional disturbance such as altered eye movement control, kinaesthetic sensibility or other symptoms of postural control such as altered balance or the perception of the visual vertical and horizontal (Treleaven, 2008, Humphreys, 2008).

Conclusion

Fifteen minutes of constant neck muscle 35% MVIC in eight different directions in the standing position produced significant altered and perceived altered balance in elite amateur rugby league players. The median frequency EMG and sway velocity were most affected during posteriorly oriented contractions.

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Key points

- Using a percentage of MVIC permits to proportionally fatigue various neck muscle groups evenly
- Fatigue of different neck muscle groups will alter balance differently
- Fatigue of muscles producing extension and posterior oblique will alter balance the most although subjects perceive a greater altered balance after lateral flexion

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Effects of cervical muscle fatigue on the perception of the subjective vertical and horizontal

Guy Gosselin* and Michael J Fagan

Abstract

Introduction: Cervical functional capacity outcome measures that are simple and reliable are urgently needed in order permit accurate assessment/reassessment during treatments and rehabilitation. Induced neck muscle fatigue has been shown to alter functional capacities such as balance and kinaesthetic sense in the standing posture. The Rod and Frame Test has also shown promise as a method of assessing the effects of chronic neck pain and injury, but currently only in the sitting position. The objectives of this project were therefore 1) to validate the computerised rod and frame test in the standing posture, and 2) to measure the effects that different cervical muscle fatigue protocol would have on the assessment of the subjective visual vertical and horizontal.

Method: The validation of the standing computerised rod and frame test in the standing posture was obtained by comparing results (n = 74) between the sitting and standing positions with the Spearman's correlation coefficient. In addition, agreement between the two methods was analysed with the Bland-Altman method.
Participants (n = 56) resisted with their neck muscles approximately 35% maximum isometric voluntary contraction force for 15 minutes on a purpose built apparatus in eight different directions. Wilcoxon signed rank tests analysed changes in horizontal and vertical rod and frame test between the neutral and all different directions of contraction. The changes of recorded unsigned vertical and horizontal errors for the combined frame condition in all situations of isometric contraction were analysed with two respective one-way repeated measures analysis of variance (ANOVA).

Discussion: The Spearman's rho and Bland-Altman plots show that the Rod and Frame Test works equally well in sitting and standing positions.
After muscle contraction, there were significant increases in error in all participants for both horizontal and vertical rod and frame tests, except after flexion. These errors were predominantly present after fatigue of muscles in the coronal plane of contraction. Proprioception alone cannot explain the difference in the rod and frame results between different muscle groups. It is suggested that an evolutionary advantage of developing improved subjective verticality awareness in the same direction as the main visual field could explain these findings.

Keywords: Muscle fatigue; Field-dependency; Rod and frame test

Introduction

There is a growing body of evidence indicating that after neck injury some parameters associated with cervical functional capacities, such as altered eye movement control, kinaesthetic sensibility, or other problems associated with distorted postural control, the change in altered balance or increased errors in the perception of the visual vertical and horizontal, may not return to the pre-injury state (Roijezon et al., 2010; Yu et al., 2011; Treleaven, 2008). In such situations, few clinicians have access to the sophisticated equipment necessary to accurately assess the neck's functional capacity. New, simpler and more accessible assessment protocols are urgently needed (Humphreys, 2008).

To that effect, some researchers have developed laboratory protocols that fatigue neck muscles in an attempt to reproduce impairments observed in subjects that have suffered a neck injury (Duclos et al., 2004; Gosselin et al., 2004; Schieppati et al., 2003; Stapley et al., 2006) or experienced cervical mechanical stress (Field et al., 2008; Gosselin and Blouin, 2000). Many of these protocols involve the subjects being tested in the standing position.

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Recently, the Rod and Frame Test (RFT) or tests measuring the perception of the subjective visual vertical (SVV) and subjective visual horizontal (SVH) have been used to study the functional effects of either neck pain or whiplash (Bagust et al., 2005; Grod and Diakow, 2002; Docherty et al., 2012). The RFT is a measure of perceptual style, and advances in technology have permitted the development of a modern version of the classic sitting rod and frame test by using a computer and video goggles described as the Computerised Road and Frame Test (C-RFT) (Bagust, 2005). Eventually, Docherty and Bagust improved the C-RFT with the use of two dots instead of a rod-line (C-RFT^{dot}) thereby decreasing the visual cues due to screen pixilation seen on the rod during the C-RFT (Docherty and Bagust, 2010).

The first goal of this work was to confirm that a modified C-RFT^{dot} method could be used reliably while participants were standing. The sitting C-RFT^{dot} test methodology as developed by Bagust (2005) was modified in order to 1) decrease the possible proprioceptive cues provided by the sitting position and by both arms touching the computer keyboard and mouse, and 2) reproduce posturographic protocols that are used in many laboratories enabling the experimenters to combine two or more tests in the standing posture. The second goal was to investigate if fatiguing different neck muscle would alter healthy subject's ability to perceive the subjective visual vertical and horizontal.

Method

Validation of C-RFT^{dot} in the standing posture

Design and subjects

Seventy (n = 74) healthy male volunteers (23 ± 2 years old; weight = 89.2 ± 6.2 kg, height = 1.82 ± 3.5 m) were recruited from local amateur rugby league and football teams. None were compensated for participating in the study. Inclusion criteria included absence of injuries within the last six months, no visual disturbance, not wearing spectacles and being fit to play. Ethical approval was obtained from the University's Ethics Committee and all participants signed a consent form after reading an information sheet. Participants were randomised into two equal groups (group A: n = 37; group B: n = 37) according to their surname. All subjects took the C-RFT^{dot} both sitting (T_1) and after 15 minutes rest in the standing position (T_2). The order of the tests was determined by a list randomiser (www.random.org). There was no time constraint to perform the tests. Subjects performed all tests in a darkened room wearing computerised video goggles (Shenzen EOS Electronics Co, Hong Kong) which effectively simulated the viewing of a 183 cm screen from a 2 m distance. Eye patches attached to the video goggles were used to help limit peripheral vision. Participants looking straight at a dark computer screen were presented with a white square acting as the frame while the head was held in the Frankfort plane (Olivier and Du Toit, 2008) (Figure 1).

C-RFT^{dot} method

Inside the square two superimposed dots were shown. The subjects were instructed to use the right and left computer mouse buttons in order to move the dots around their imaginary centre in clockwise or counter clockwise paths. The dots' movements were made in 0.5° increments up to a maximum of 30° rotation from the vertical in either direction. A pre-programmed session of 18 situations was presented where there was 1) an absence of the square; 2) the square frame levelled (0°, frame°); 3) square frame angled clockwise +18° (frame^{+18}); or 4) square frame angled counter clockwise −18° (frame^{-18}). All situations recurred randomly four times as determined by the programme and two additional practice situations completed the test with the dots angled clockwise (+20°) or counter clockwise (−20°) (Docherty and Bagust, 2010). Participants were asked to move the dots as close as possible to their perception of the gravitational vertical or horizontal. Once they had confirmed the alignment using the space bar, the image would clear and the next sequence would appear. Participants would take on average between two and four minutes to complete the test. The second set (T_2) of experiments was performed during quiet stance with the arms relaxed to the side of the body. Participants held a hand held mouse to control the dots and validate the test sequence which permitted the arms to remain at the side of the body (Figure 2).

Neck muscle fatigue protocol

Fifty six (n = 56) participants that took part in the validation study volunteered to participate on different days in the neck fatigue experiment. None were compensated for participating in the study. Participants were randomised into two equal groups (group A: n = 28; group B: n = 28) according to their surname. Neck muscle fatigue was induced by the participants undertaking isometric contractions (Schieppati et al., 2003; Gosselin et al., 2004). They were asked to stand comfortably, the feet comfortably apart,

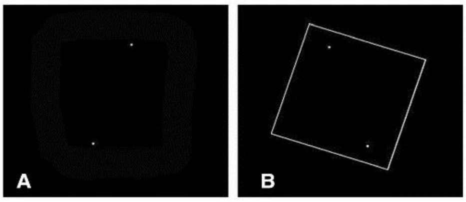

Figure 1 Computer sceen capture of test. A Dots. **B** Dots and tilted frame (at +18°).

Figure 2 C-RFT^{dot} positions. A. Participant 's sitting at a desk and controls the mouse with the right hand while the left hand validates the trial. **B.** Standing position. The participant controls the dots and validates the trial with one hand. **C.** Close up view of the hand held mouse in the participant's hand.

with their arms to their side and leaning slightly towards a support pad. This was provided to help stabilise body movement during the experiment, and was part of a custom built supporting structure (Figure 3). A head weight training harness was placed on the participant's head, from which a cable extended horizontally and was attached via a pulley system to an appropriate mass. No significant contraction of the body thoracic or lumbar muscle chain below the level of the support was assumed required. A marker was attached to the pulley and the experimenter observed if the pulley remained co-planar with a reference point fixed to the supporting structure. During the isometric contraction, the experimenter would give a verbal cue in order for the participant to either increase or decrease the cervical muscle force against the weight thereby maintaining a static head/neck position. Eight different positions were used each at a 45° offset from the previous one (Figure 4). The orientation of efforts were in extension (E), right posterior oblique (RPO), right lateral flexion (RLF), right anterior oblique (RAO), left posterior oblique (LPO), left lateral flexion (LLF), left anterior oblique (LAO) and flexion (F) (Figure 4). In order to decrease bias due to a participant's overexertion, the experiment was conducted over two days. On day one, Group A was tested in four different directions each at 90°

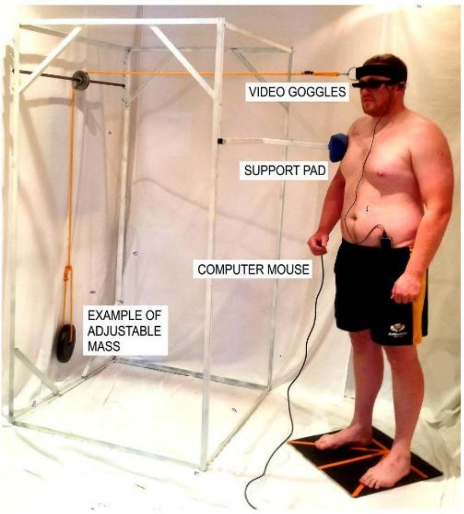

Figure 3 Experimental setup showing the participant performing an isometric contraction. The orientation of contraction is in the left posterior oblique direction (LPO). The participant is holding a computer mouse in the right hand. The effort is produced against a cable placed over a pulley to an adjustable mass.

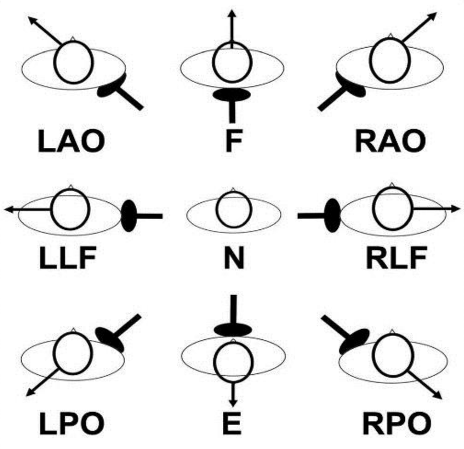

Figure 4 The orientation of efforts. Neutral position (N), Extension (E), right posterior oblique (RPO), right lateral flexion (RLF), right anterior oblique (RAO), left posterior oblique (LPO), left lateral flexion (LLF), left anterior oblique (LAO) and flexion (F).

from the other: E, F, RLF, LLF; on day 2: RPO, LPO, LAO, RAO. The order was reversed for Group B.

The load set on the cable was approximated to 35% of the maximum isometric voluntary contraction as used by Stapley and Schieppati (Stapley et al., 2006; Schieppati et al., 2003) (Table 1). In order to avoid risks of injuries during maximum voluntary contraction measurements, the load was instead calculated individually for each participant by using the isokinetic neck strength profile of elite rugby players and healthy adults (Olivier and Du Toit, 2008; Hogrel et al., 2007). The mass in kilograms required for each participant for a particular movement was then obtained by dividing the peak torque presented in the database by the participant's neck length and gravitational constant (9.81 m/s^2). Neck length was measured from the spinous process of the vertebral prominence (C7) to the occipital notch at the base of the skull, while the head was held in the Frankfort plane (Olivier and Du Toit, 2008).

Due to the absence of normative data for the oblique contractions, we averaged the torque from either the extension and lateral flexion or the lateral flexion and flexion. For example, the RPO load was determined by averaging the E and RLF torques.

Isometric muscle contraction and C-RFT^{dot} procedures

The participants stood in a relaxed stance in one of the predetermined positions with their body approximately 2 cm away from the padded vertical support of the apparatus. The C-RFT^{dot} was started. Once the C-RFT^{dot} completed, the head weight training strap was applied to the head and the appropriate weight placed at the end of the cable. During the neck extension muscle sequence, the participants were instructed to lean against the padded vertical support and thus maintain the position of the head and neck, and to readjust the position should the experimenter give them a verbal cue.

After 15 minutes of isometric contraction, the experimenter immediately removed the head weight training straps from the participant's head and asked the participant to hold a comfortable standing position. Once their position had stabilised, the second C-RFT^{dot} test was started. Participants were allowed 15 minutes recuperation between experimental situations. Overall, the experimentation of the four situations lasted between 2.15 to 2.45 hours.

Analysis

Each participant's errors in aligning the rod were used to calculate the absolute means or unsigned or signed values for each of the eight test situations. The direction of the error was determined by the average signed results which indicated the direction of errors whilst the magnitude was determined by the absolute errors. All analyses were performed using SPSS 17.0 and GraphPad Prism 6. Data were tested for normality using the Shapiro-Wilk test. The data are given as median ± standard deviation (SD). As our data were not normally distributed, we looked for correlation between sitting and standing C-RFT^{dot} results with the use of the Spearman's correlation coefficient test. Furthermore, agreement between the two methods was analysed with the Bland-Altman method on signed errors.

Wilcoxon Signed-Rank tests were used to determine if there were differences in the absolute C-RFT^{dot} errors between the neutral positions and all other eight directions of contraction. Wilcoxon signed rank tests therefore analysed changes in horizontal and vertical C-RFT^{dot} errors between the neutral and eight different directions of contraction. The changes of recorded C-RFT^{dot} unsigned (absolute) vertical and horizontal errors for the combined frame condition in all eight situations of isometric contraction were analysed with two respective one-way repeated measures analysis of variance (ANOVA) with

Table 1 The masses and loads used by the participants for a particular movement

Direction	E	RPO	RLF	RAO	LPO	LLF	LAO	F
Average torque (Nm)	56.2	59.5	59.7	50.5	59.5	58.9	50.5	38.9
Peak mass (kg)	54	57.2	57.4	48.6	57.2	56.6	48.6	37.4
35% Peak mass (kg)	18.9	20.0	20.1	17.0	20.0	19.8	17.0	13.0

Greenhouse-Geisser (1 factor, 8 levels). The Bonferroni correction was used as post-hoc tests. The use of a parametric test for non-normally distributed data can be justifiable because, even with non-normal distributions at the participant level, with a large enough sample size, such as in our case (n = 56), the distributions of the sample means become sufficiently normal for the ANOVA to be robust enough to analyse the data (Lumley et al., 2002). Significance levels were set at 0.05.

Results

Validation

Shapiro-Wilk test shows that the recorded positioning errors are not normally distributed ($p < .001$), as shown in Figure 5. The results suggest that the relationship between the C-RFT^{dot} absolute errors in the sitting and standing positions is highly significant for the SVV (rho = 0.982, $p = 0.01$) and for the SVH (rho = 0.950, $p = 0.01$). The Bland-Altman analysis indicates that the 95% limits of agreement between the two methods ranged from −1.49 to 1.11 vertically and −1.33 and 1.48 horizontally (Figure 6). The two methods consistently provide similar measures.

RFT^{dot} after isometric contraction

Wilcoxon Signed-Rank tests showed there were statistically significant increases in errors in all subjects both for the horizontal and vertical C-RFT^{dot}, except after flexion both in the horizontal and vertical C-RFT^{dot} (Tables 2 and 3).

Vertical and horizontal errors with and without tilted frames are shown in Figure 7. When no frame was present, there were significant differences ($p < .01$) in the C-RFT^{dot} after contractions in all directions except after E

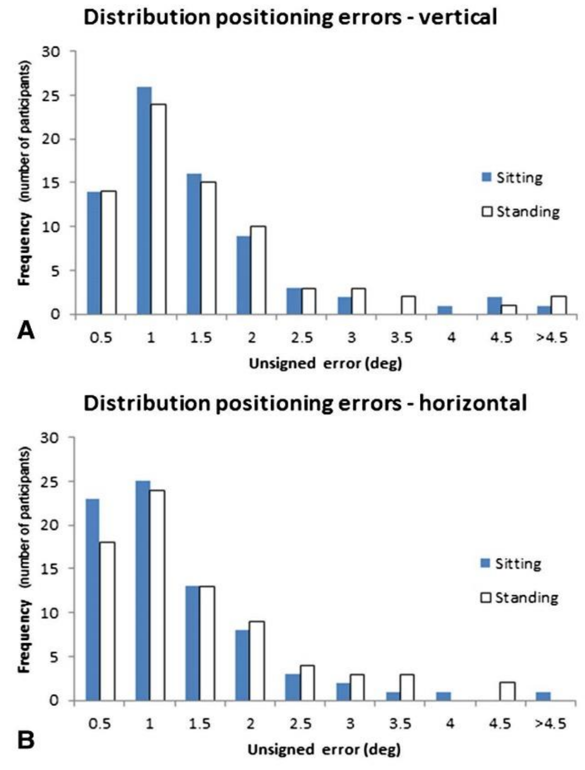

Figure 5 Distribution of the unsigned errors for the combined frame^{+18} and frame^{-18} values. (A) Vertical, **(B)** Horizontal.

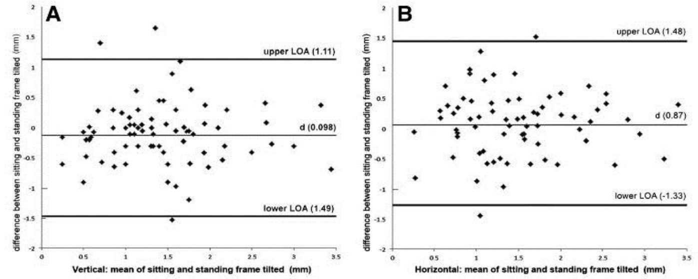

Figure 6 Bland-Altman analysis of agreement between sitting and standing C-RFTdot results, (A) Vertical mean of sitting and standing frame tilted (mm) showing the 95% limits of agreement between 1.49 mm and 1.11 mm, (B) Horizontal mean of sitting and standing frame tilted (mm) showing the 95% limits of agreement between −1.33 mm and 1.48 mm horizontally.

and F on the horizontal test and E, F, RPO and LPO on the vertical test. The effect of tilting the frame 18° clockwise or counter clockwise caused significant increased positioning errors in all situations ($p < .001$) although there was no difference between the unsigned means of the clockwise and counter clockwise tilted frame for both horizontal and vertical results. More importantly, the direction of contraction did not influence the sign of the positioning errors.

When frames were present the one-way repeated measures ANOVAs with Greenhouse-Geisser corrections determined that different directions of 15 minutes isometric contractions produced significant changes between differences in C-RFT^{dot} (vertical errors: $F(4.176, 233.830) = 55.272$, $p < .001$; horizontal errors: $F(3.839, 215.005) = 50.699$, $p < .001$). Post hoc tests using the Bonferroni correction revealed that changes in C-RFT^{dot} errors were predominantly present in the transverse plane of contraction for both the C-RFT^{dot} vertical and horizontal (Figure 8). There were no significant differences between C-RFT^{dot} horizontal E and F contractions in the sagittal plane ($p > 0.6$) nor were there C-RFT^{dot} vertical mean differences between the RPO, RAO, LPO; RLF, LLF; LPO, RPO, LAO. Figure 9 helps to visualise the differences vertical and horizontal combined unsigned errors.

Discussion

Our results showed that participants obtained highly correlated scores on the C-RFT^{dot} whilst sitting or standing, but this nonetheless did not confirm agreement between the two methods. The Bland-Altman test was designed specifically to test such an agreement between two experimental methods (Bland and Altman, 1986; Bland and Altman, 2010). We therefore considered both sitting and standing situations as field methods and plotted differences against their mean value. (Since we were comparing different test positions, it was not considered appropriate to assign the sitting position as the reference (Gold Standard) and plot differences against that (Mantha et al., 2000)).

Table 2 Combined horizontal +18^{+} and −18 scores for each isometric contraction direction

Direction	Mean/SD	Median	IQR	CI 95%	z	*p*
E	2.22 ± 1.0	2.3	1.2–2.9	1.9–2.4	−4.026	.001
RPO	3.8 ± 0.8	3.9	3.3–4.4	3.6–4.0	−6.314	.001
RLF	8.22 ± 4.1	7.2	4.8–12.2	7.1–9.3	−6.535	.001
RAO	4.35 ± 2.5	3.8	2.8–4.8	3.7–4.9	−6.313	.001
LPO	4.32 ± 2.4	3.9	2.4–6.2	3.7–4.9	−6.488	.001
LLF	7.67 ± 3.6	7.1	4.8–9.5	6.7–8.6	−6.568	.001
LAO	3.78 ± 1.8	2.9	2.4–5.8	3.3–4.2	−6.163	.001
F	1.76 ± 0.8	1.8	1.4–2.2	1.5–1.9	-.341	**.733**

Table shows mean and standard deviation, median, Interquartile range (IQR), lower and upper 95% confidence interval of the difference, and the Wilcoxon paired rank z statistic and significance.

Table 3 Combined vertical +18 and −18 scores for each isometric contraction direction

Direction	Mean/SD	Median	IQR	CI 95%	z	*p*
E	2.29 ± 1.0	2.2	1.6–3.0	2.2–2.6	−2.015	.044
RPO	3.86 ± 1.1	3.8	3.4–4.2	3.5–4.1	−6.520	.001
RLF	6.82 ± 2.6	7.1	4.2–9.4	6.2–7.6	−6.567	.001
RAO	4.27 ± 2.7	3.5	2.2–4.8	3.6–5.0	−6.309	.001
LPO	4.5 ± 1.63	4.4	3.8–4.8	4.1–4.9	−5.618	.001
LLF	7.01 ± 3.0	6.2	4.3–9.5	6.2–7.9	−6.567	.001
LAO	3.82 ± 1.3	3.8	3.4–4.2	3.5–4.2	−5.939	.001
F	1.57 ± 0.75	1.5	1.3–1.66	1.4–1.8	-.029	**.977**

Table shows mean and standard deviation, median, Interquartile range (IQR), lower and upper 95% confidence interval of the difference, and the Wilcoxon paired rank z statistic and significance.

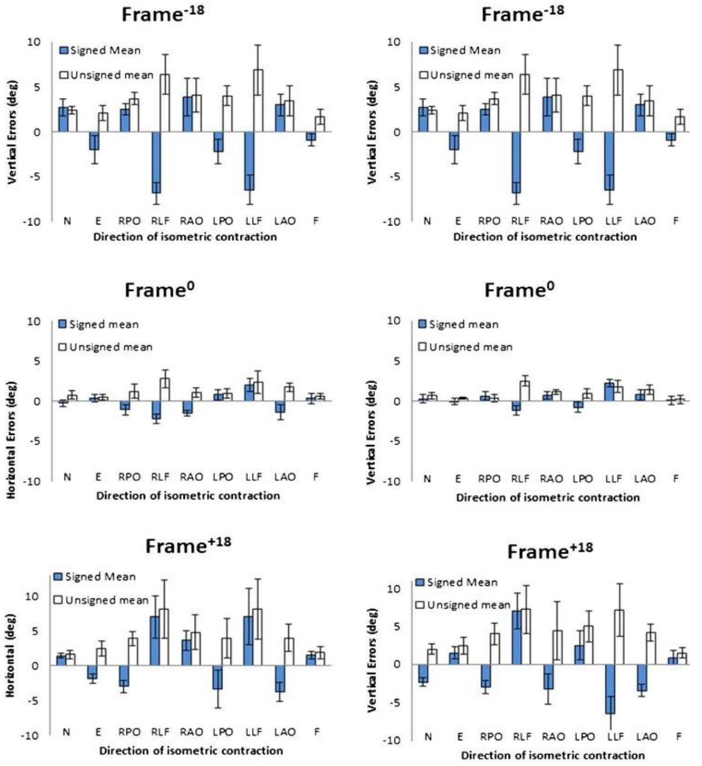

Figure 7 Vertical and horizontal errors with the frame at frame^{-18} frame^{0} and frame^{+18}. Errors presented in degrees with standard deviations.

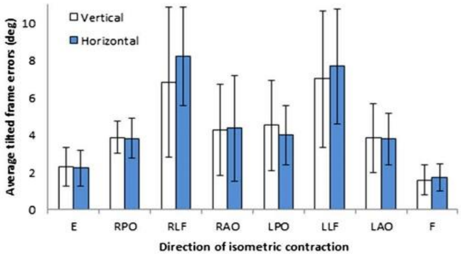

Figure 8 The vertical and horizontal unsigned combined +18 and −18 scores for each isometric contraction direction. The largest positioning errors in mm are seen after lateral contraction. Error bars are the standard deviation.

Bagust (Bagust et al., 2005) found no significant difference between the no frame and frame^{0} whilst testing participants in the sitting position. Our results indicate that even without a frame or in the presence of a frame^{0}, a neck fatigue protocol does indeed affect the participant's ability to perceive accurately the subjective vertical and horizontal in all directions of contraction, except after contractions in the sagittal plane (extensor and flexion). Panichaporn also reported this absence of significant change after fatiguing neck extensor muscles at 33.3% MVIC for five minutes (Panichaporn et al., 2013). It is interesting to note that although neck extensor and flexor muscles fatigue did not change the C-RFT^{dot} results, the muscles themselves are quite different from each other both in structure and function. The density of muscle spindles is higher in the small intrinsic, deep

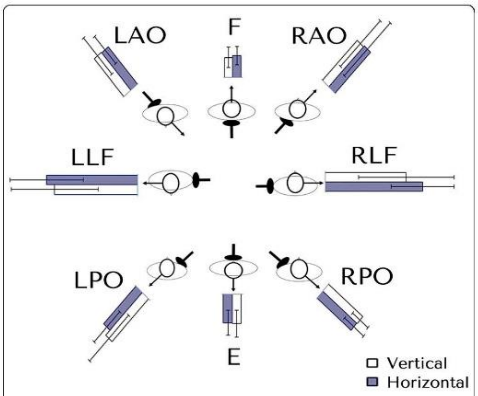

Figure 9 Graphical representation of the vertical and horizontal combined +18 and −18 scores for each isometric contraction direction. Extension (E), right posterior oblique (RPO), right lateral flexion (RLF), right anterior oblique (RAO), left posterior oblique (LPO), left lateral flexion (LLF), left anterior oblique (LAO), and flexion (F).

dorsal and suboccipital cervical muscles than in other cervical muscle groups which accounts for their important role in proprioception (Peck et al., 1984; Rix and Bagust, 2001). These findings suggest three main effects. Firstly, proprioception alone cannot explain the difference in C-RFT^{dot} scores between muscles fatigued in the sagittal plane and muscles fatigued in the frontal or oblique planes. This is supported by Funabashi's findings that the use of a neck brace does not provide sufficient afferent input to change a healthy subject's perception of visual verticality (Funabashi et al., 2011). Additional support for the visual inputs overriding cervical proprioception has been demonstrated in various studies (Karnath et al., 2002; Golomer et al., 2005). For example, Schieppatti showed that the effect of the neck muscle fatiguing contractions did not significantly affect postural sway when vision was allowed (Schieppati et al., 2003). Secondly, these results also support the rejection of the standard model of peripheral fatigue as inadequate to explain the selective effects on the C-RFT^{dot} scores (Noakes et al., 2005).

Lastly, studies on primates has shown that in simpler forms, the midbrain constitutes a mechanism capable of organizing general orienting movements of eyes, head and trunk within the visual fields and controlling associated patterns of contraction in the proximal musculature. The improved perception of vertical has been reviewed in discussion of chimpanzees and hominids bipedalism where this developed mechanism in demanding positions has been suggested to rely on an innate spatial gravitational self-awareness in relation to the ground reaction force (Stanford, 2006; Skoyles, 2006). Presumably the arboreal habitat of early primates imposed selective pressure which favoured the evolution of vision resolving special problems during locomotion. For specific motor behaviour such as fixating a target, it is essential to identify accurately the object in relation to the head. Primates' brain use abstract, neural imaging of space between sensory and between motor output. These representations seem to be arranged in non-retinal, egocentric coordinates. Therefore, these egocentric references were shown for some time to be intimately associated with perception of body orientation in the sagittal plane such as in the subjective straight ahead experimentations (Karnath et al., 2003; Karnath, 1994). We therefore suggest that the absence of effects after contractions of muscles in the sagittal plane may be related to an evolutionary advantage of developing improved subjective verticality awareness in the same direction as the main visual field even in the presence of disturbances such as muscle fatigue or injury. It has also been reported since the early twentieth century that maximum acuity occurred with horizontal and vertical orientation (Emsley, 1925). Latto suggested that the dominance of visual orientation in perception was that more Hubel and Wiesel orientation detectors in the visual cortex were turned to horizontal and vertical than to oblique lines and edges (Atto and Russel-Duff, 2002). In addition, even though 15 minutes of muscle contraction did increase the errors recorded in the plane of contraction when a frame was present, contrary to other studies, there was no significant difference in the direction of errors recorded (Docherty et al., 2012; Docherty and Bagust, 2010). This phenomenon is reminiscent of motor post-effects seen after short duration isometric contractions (Duclos et al., 2004). The neurophysiological processes underlying these observations are unknown but are similar to observed displacement along the same plane seen in the Kohnstamm phenomenon (Ivanenko et al., 2006).

Takasaki recently studied the minimum repetitions for stable measures of visual dependency using the C-RFT^{dot} (Takasaki et al., 2012). He concluded that instead of the usual four repetitions, five should be used so that the C-RFT^{dot} could give consistent measures of deviation from the vertical in asymptomatic healthy individuals. However, during the validation part of our project, we consistently obtained comparable results to previous C-RFT^{dot} reports which confirms that our method was acceptable (Docherty et al., 2012; Docherty and Bagust, 2010). The higher minimum numbers of repetitions reported by Takasaki could be due to the additional visual feedback provided to their participants by the modified computer program they used in their experiment. Instead of presenting participants with just a white tilted/untilted square frame and two dots on a black background as we have done in our own experiment, Takasaki added a control panel interface on the screen with which the participants were required to move the dots by dragging and turning a button created on the lower right screen using a computer mouse. This additional object in the visual field represents a significant difference in the methods used because the previous C-RFT^{dot} studies have attempted to minimise participant's visual cues whilst Takasaki actually increased visual cues. We therefore feel confident that our results are a true representation of the participant's capacities.

It has been shown that high-level athletes participating in open-skills activities specifically involving contact were more field-dependant compared to medium level athletes (Liu, 2003; Liu, 1996). Our participants did not appear to be particularly field-dependant although their results showed less variance than previous C-RFT^{dot} studies. This could be attributed to the highly homogenous group of participants playing mostly the same sport with similar age, skills and level of fitness compared to previous studies presenting more heterogeneous volunteers. A more heterogeneous group of participants or a more field-dependent group of participants could have produced different results. The participants in this study were men therefore caveats should be stated before our results can be applied to other population groups such as neck pain sufferers because woman are more likely to suffer from neck pain than men (Cote et al., 2004).

Our results show that in our participants different muscle groups react differently to disturbances such as isometric muscle contraction. We already know that balance is altered after neck extensor muscle fatigue protocols (Schieppati et al., 2003; Duclos et al., 2009; Gosselin et al., 2004) or after whiplash injuries (Stapley et al., 2006; Field et al., 2008). What is still unknown is what effect injuries to specific muscles groups will have on these functional properties. We have recently completed a study with elite amateur rugby league players on the effects of cervical muscle fatigue protocol on balance (Gosselin et al., 2014). The results show a clear trend from the highest velocity after posterior muscle groups were contracted (E, ROA, RPO) towards the lowest velocity change after flexor muscles contraction (F, LAO, RAO). These results are quite striking when placed in context with the present study as we observe for the first time that neck flexor and extensor muscle groups do not appear to play a significant role in our space awareness abilities as initially thought which support the use of the C-RFT^{dot}. We have shown that extensors and lateral flexors appear to be major contributing factors to cervical functional capacities These findings represent important new elements that should be investigated further in order to develop clear outcome and rehabilitation protocols.

Conclusion

Our experiment has demonstrated that both sitting and standing C-RFT^{dot} methods produce statistically identical results. Furthermore, 15 minutes of constant neck muscle contraction at approximately 35% MVIC in eight different directions in the standing posture increased significantly the C-RFT^{dot} positioning errors in all directions except in the sagittal plane. Proprioception alone cannot explain this phenomenon and it is suggested that an evolutionary advantage of developing improved subjective verticality awareness in the same direction as the main visual field could explain these findings. Further study on the functional role of muscles acting in the frontal plane is encouraged.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
GG designed, executed and analysed the entire experiment and prepared the manuscript. MF assisted in design as well as in the preparation of the manuscript. Both authors read and approved the final manuscript.

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- Brief description of statistical tests used

Shapiro-Wilk

The Shapiro–Wilk test is a test of normality in frequentist statistics. Frequentist statistics is the inference framework in which the well-established methodologies of statistical hypothesis testing and confidence intervals based

t-test

A statistical examination of two population means. A two-sample t-test examines whether two samples are different and this test is commonly used when the variances of two normal distributions are unknown and when an experiment uses a small sample size.

Analysis of variance (ANOVA)

Analysis of variance is a collection of statistical models used to analyse the differences between group means and their associated procedures (such as "variation" among and between groups),

Repeated measures analysis of variance (ANOVA)

Repeated measures ANOVA is a parametric test that is the equivalent of the one-way ANOVA, but for related, not independent groups, and is the extension of the independent t-test. This test is used to detect any overall differences between related means between more than two groups.

Wilcoxon Signed Ranks Test

The non-parametric Wilcoxon Signed Ranks test is designed to test a hypothesis about the location (median) of a population distribution. It often involves the use of matched pairs, for example, before and after data, in which case it tests for a median difference of zero. The Wilcoxon Signed Ranks test does not require the assumption that the population is normally distributed

Greenhouse-Geisser correction

The Greenhouse-Geisser procedure estimates epsilon (referred to as $\hat{\varepsilon}$) in order to correct the degrees of freedom of the *F*-distribution when sphericity has been violated. Sphericity is when the variances of the differences between all combinations of related groups are not equal.

Bonferroni correction

The Bonferroni correction is an adjustment made to *P* values when several dependent or independent statistical tests are being performed simultaneously on a single data set

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