SMART PHONE ASSESSMENT OF POSTURAL SWAY IN CHRONIC NECK PAIN SUFFERERS

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INDIGENOUS ACKNOWLEDGEMENT

The researcher wishes to acknowledge the traditional custodians of the land

where the research project was completed and pay respect to

all past and present elders of The Ngunnawal and Ngambi Tribes.
Patients with chronic neck pain (CNP) often describe the presence of associated symptoms such as unsteadiness, dizziness, light-headedness, loss of standing balance and a sensation of falling, as well as a history of increased incidence of actual falls. Effectively assessing balance in these patients would assist in their differential diagnosis, on-going management and the determination of treatment intervention(s) leading to improved rehabilitation outcomes and, potentially, a reduction in the likelihood of fall-related injuries.

Research has demonstrated the relationship between chronic neck pain and disturbances of balance by measuring alterations of postural sway (PS) with computerised force plates (CFP) and / or posturography. Whilst providing reliable measurements of postural sway, the equipment is not readily available and is expensive for use in the clinical practice environment. New generations of Smart Phones (SP) with inbuilt sensors are capable of measuring metabolic energy expenditure, cardiovascular responses and gait parameters. However, no study to date has shown if a Smart Phone, with an embedded accelerometer sensor and application (App) establishing a wearable accelerometer (WA), can measure postural sway in patients with chronic neck pain.

The primary aim of the study was to determine if Smart Phones can provide valid measures of postural sway in chronic neck pain sufferers, relative to the reference standard computerised force plates. The secondary aims were to investigate the relationship between the self-rating of pain and disability and mechanical pain...
threshold test (MPTT) measures, and the relationship of both of these measures with postural sway in participants with and without chronic neck pain.

To determine these aims control and chronic neck pain test groups, each with 25 participants, were simultaneously measured for postural sway during five clinical balance tests (three static and two dynamic / functional) with computerised force plate and Smart Phone. The participants were also assessed for demographic and related medical history information: completed physical (height, weight, foot size & width, body mass index (BMI)) and pressure algometric (symptomatic & asymptomatic locations) measurements: and answered five self-rating questionnaires (VAS Pain, VAS Stress, NDI, DASS – 21, SF – 36). Spectral analysis produced frequency-domain measures (filtered 0-12 Hz) of Raw Standard Deviation (RSD), Root Mean Square (RMS), and Fast Fourier Transform (FFT) Mean and Maximum Frequencies. Statistical analyses employed independent t-tests and bivariate Pearson’s r correlations, while inferential statistics utilized Cohen’s criteria (Cohen, 1988).

The result analyses for “all participant data combined” indicated the most valid frequency-domain measure for assessing postural sway using the Smart Phone was FFT Mean frequency. This measure recorded eleven significant positive Pearson’s r correlation coefficients between the computerised force plate and Smart Phone measures ranging from small to large effect sizes ($r = .28 - .53; p < 0.01$). Similarly valid measures were the RSD, with four significant small to large positive Pearson’s r correlation coefficients ($r = .29 - .79; p < 0.01$), and the FFT Maximum frequency, with four medium to large positive ($r = .40 - .53; p < 0.01$) correlations. The least valid measure was the RMS, with only one medium significant Pearson’s r correlation coefficient ($r = .33; p < 0.05$) when compared to the computerised force plate.
Analysis of each of the three axial accelerometer directions (vertical, anterio-posterior (AP) and medio-lateral (ML) directions) for FFT Mean frequency data demonstrated significant positive Pearson’s $r$ correlation coefficients in all three axial directions for the single leg stance (SLS) and tandem walking (TW) balance tests ranging from medium to large ($r = .3 - .49; p < 0.01$). Although for both test groups the FFT Mean frequency measure produced a similar number of significant Pearson’s $r$ correlation coefficients for both AP and ML directions, the AP direction produced a stronger correlation for all balance tests ranging from medium to large ($r = .46 - .53; p < 0.01$).

For the Control Group FFT Mean frequency again was demonstrated to be the most valid frequency-domain measure in all three axial directions with ten significant positive Pearson’s $r$ correlation coefficients between the computerised force plate and Smart Phone measures ranging from medium to large effect sizes ($r = .42 - .58; p < 0.01$). For the Chronic Neck Pain Group FFT Mean frequency was the most valid frequency-domain measure but only in the AP direction, with five significant Pearson’s $r$ correlation coefficients between the computerised force plate and Smart Phone measures of medium effect size ($r = .41 - .49; p < 0.01$).

Independent samples $t$-tests for the FFT Mean frequency measure revealed no significant difference between the control and chronic neck pain groups for either the computerised force plate or Smart Phone techniques for assessing postural sway.

The relationship between Smart Phone postural sway and self-ratings of pain and disability measures revealed a greater number of significant Pearson’s $r$ correlation coefficients, ranging from medium to large ($r = .4 - .58; p < 0.05$), than the computerised force plate. Similarly, the relationship between Smart Phone postural
sway and mechanical pain threshold test measures showed the same trend (a greater number and stronger significant Pearson’s $r$ correlation coefficients ranging from medium to large ($r = .46 - .57; p < 0.05$) than the computerised force plate). Measures of the relationship between self-rating of pain and disability and mechanical pain threshold test demonstrated significant positive Pearson’s $r$ correlation coefficients for the self-perceived pain and physical health disability measures ranging from medium to large ($r = .4 - .53; p < 0.05$).

The results of the study suggest that Smart Phone measures of postural sway in the general population are valid when compared to those of the computerised force plate. In chronic neck pain sufferers Smart Phone accelerometer measures are valid in the AP direction during the more challenging single leg stance and tandem walking balance tests. Potentially the most valid frequency-domain measure for assessing postural sway is the FFT Mean Frequency, again particularly in the AP direction during the more challenging balance tests of single leg stance and tandem walking. Relative to the computerised force plate, the Smart Phone better demonstrates the relationship between postural sway and self-rating pain and disability measures. This relationship is most consistent for the more challenging balance tests of single leg stance and tandem walking and is best assessed by the DASS-21 questionnaire, a self-rating of depression, anxiety and stress. Lastly, the relationship between the various self-rating of pain and disability scores and mechanical pain threshold test measures are only evident for the physical health summary component in chronic neck pain sufferers.

In conclusion, the Smart Phone with appropriate software, used as a wearable accelerometer, has the potential to become an inexpensive and easily accessible
technique for quantitatively measuring postural sway suitable for the clinical practice environment. Used in conjunction with carefully selected self-rating questionnaires and mechanical pain threshold test measures, the Smart Phone could allow earlier detection and potentially better on-going monitoring of changes in postural sway. This may enable immediate assessment of treatment interventions leading to improved rehabilitation outcomes and a reduction in the likelihood of falls-related injuries in chronic neck pain sufferers from balance disturbances. Potentially these benefits of Smart Phone technology could also be used with sufferers experiencing balance disturbances arising from other orthopaedic, sports, neurological, geriatric or paediatric conditions.
PUBLICATIONS AND PRESENTATIONS

Peer - Reviewed Journal Article under Review

1. **Rumore, A.J.,** Waddington, G. & Cathcart, S. Validity of Smart Phone Measures of Postural Sway – *PLOS Medical Journal*

Peer - Reviewed Conference Presentations

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ABBREVIATIONS

AIHW = Australian Institute of Health and Welfare

AP = Anterior-Posterior

APi = Articular Pillar

BMI = Body Mass Index

BPM = Balance Performance Monitor

C = Cervical

CFP = Computerised Force Plate(s)

CNP = Chronic Neck Pain

CNS = Central Nervous System

CoG = Centre of Gravity

CoM = Centre of Mass

CoP = Centre of Pressure

CP = Chronic Pain

CS = Comfortable Stance

CSV = Comma Separated Value
DASS – 21 = Depression (D) Anxiety (A) Stress (S) Scales (21)

df = Degrees of Freedom

E / F = Energy / Fatigue

EW – B = Emotional Well Being

F = Levene’s Test for Equality of Variances

FETR = Fisher’s Exact Test Result

FFT = Fast Fourier Transform

GH = General Health

GIS = Geographical Information Systems

GPS = Global Positioning System

IASP = International Association for the Study of Pain

ICC = Intraclass Correlation Coefficient

kPa = Kilo Pascals

M = Mean

ML = Medio-Lateral

MPTT = Mechanical Pain Threshold Test

n = Number
NA = Not Answered

NDI = Neck Disability Index

NS = Narrow Stance

NSAID = Non-Steroidal Anti-Inflammatory Drugs

NW = Normal Walking

$\rho$ = Significance

P = Pain

PA = Pressure Algometer

PF = Physical Functioning

PPT = Pressure Pain Threshold

PS = Postural Sway

$r$ = Pearson’s Product-Movement Correlation Coefficient


RL – PH = Role Limitation – Physical Health

RMS = Root Mean Square

RSD = Raw Standard Deviation

SCR = Skin Conductance Response
SD = Standard Deviation

SF= Social Functioning

SF-36 = Short Form Health (36) Survey

SLS = Single Leg Stance

SNS = Sympathetic Nervous System

SP = Smart Phone

SRQ = Self Rating Questionnaires

TW = Tandem Walking

VAS = Visual Analogue Scale

WA = Wearable Accelerometer

WAD = Whiplash Associated Disorders
CHAPTER 1

INTRODUCTION

1. Overview

As a titled musculoskeletal physiotherapist with a special interest in the treatment of chronic neck pain (CNP) disorders, I am aware of a subgroup of CNP sufferers who report symptoms associated with balance disturbances and a high incidence of falls-related injuries. Measuring balance in the clinical practice environment usually requires clinical balance tests known to have poor inter-tester reliability and which are potentially subject to tester bias (Sibley, et al., 2113; Gill, et al., 2011). The accepted “gold-standard” reference technique for quantitatively measuring balance is the laboratory-grade computerised force plate (CFP) (Clark, et al., 2010; Haas & Burden, 2000; Piirtola & Era, 2006). However, this equipment is expensive, lacks portability and associated accessibility and, consequently, is rendered of limited use in the clinical practice environment.

A need exists for an accurate, inexpensive and easily accessible tool for quantitatively measuring postural sway that is suitable for daily use in the clinical practice environment. If such a tool was available, it could enable earlier detection, better ongoing monitoring and immediate assessment of treatment interventions of balance disturbances in CNP sufferers and could lead to improved rehabilitation outcomes and a reduction in the likelihood of falls-related injuries.
The chapter presents an outline of two significant clinical phenomena: chronic neck pain and accidental falls, their prevalence in our society and subsequent financial burden. Following this outline is an overview of the role of balance mechanisms in accidental falls and the current techniques used to assess balance and CNP. The relationship, and associated underlying mechanisms, between CNP, sensorimotor disturbances and balance and factors influencing CNP and postural sway are also presented. Arising from the literature review, two research gaps are explored: (1) the need for an accurate, inexpensive and easily accessible technique to quantitatively assess balance in the clinical environment; and, (2) the need to determine the influence of the sensory and affective components of pain (using self-rating questionaries and mechanical pain threshold testing (MPTT) measures) on postural sway in CNP sufferers. The chapter concludes with two research questions and the associated aims and objectives of the thesis.

2. Literature Review Strategy

A preliminary literature review was conducted from August 2011 to February 2012 to develop and prepare the research proposal. The literature search was conducted on the Medline database, since previous researchers in the field have found that between 2000 - 2004 MEDLINE captured the vast majority (over 95%) of citations in a review of the neck pain literature (Carroll et al., 2008). The search revealed 23 relevant articles.

A further more comprehensive review of the electronic databases was conducted between May and September 2012 and repeated in February 2013 to expand the preliminary Medline database review. To date, 227 articles have been identified and
sourced for this research. The latter comprehensive systematic review searched the following five electronic databases using the EBSCO (Host) platform:

1. Medline
2. Science Direct
3. SPORTS Discus
4. CINAHL

The preliminary and comprehensive literature reviews employed the following keywords / terms or their combinations in the search strategy:

1. Neck Pain
2. Balance
3. Falls
4. Postural Sway (PS)
5. Computerised Force Plate (CFP)
6. Mobile Computing Platforms
7. Smart Phones (SP)
8. Wearable Accelerometers (WA).

No date or search limiters were placed on either the preliminary or comprehensive literature review searches. As recommended by Fejer, Kyvik, and Hartvigsen (2006), screening of the references cited in studies selected from the comprehensive online search and the use of thesaurus terms (MeSH terms in Medline), were undertaken to achieve a complete retrieval of all relevant literature. Filtering of the relevant literature was carried out by cross-matching all the keywords, removal of non-English
studies and review of the selected articles’ abstracts. Finally, a refining process of the keywords was undertaken to identify the articles with greatest relevance to the study, e.g. “neck pain” for “chronic or persistent neck pain”. All citations were then entered into a bibliography management software program - Endnote (X6). The most relevant 215 articles are cited and acknowledged within the thesis.

3. Chronic Neck Pain (CNP)

Chronic pain (CP) is a complex bio-psycho-social phenomenon defined by the International Association for the Study of Pain (IASP) “as pain that has persisted beyond the normal healing time of injured tissue, that being a period of time longer than three months” (Merskey & Bogduk, 1994). CP is a surprisingly common condition in Australia. In 2007, around 3.2 million Australians (1.4 million males and 1.7 million females) were estimated to have experienced CP, costing the country approximately $35 billion a year (BUPA, 2007). Sufferers with CP are also known to utilise health care services up to five times more frequently than the rest of the population (Von Korff, Ormel, Keefe, & Dworkin, 1992).

Chronic neck pain disorders are one of the most common and financially costly health complaints in the industrialized world. For example, in the Netherlands during 1996 the total cost of CNP was estimated to be 1% of the total health care expenditure or 0.1% of Gross Domestic Product (Borghouts, Koes, Vondeling, & Bouter, 1999). Prevalence estimates of CNP are not influenced by age or occupation, but women are reported to present more often and with greater severity of neck pain than men (Fejer, et al., 2006). In addition, researchers have found 70% of the general population report at least one episode of CNP during their lifetime, whilst recurrent neck pain or
episodes lasting longer than 6 months were reported in 14% of the general adult population (Côté, Cassidy, Carroll, & Kristman, 2004).

4. Accidental Falls and Balance

Accidental falls are defined “as a sudden, unintentional change in position causing the individual to land at a lower level” (Tinetti et al., 1994) and are the leading cause (38%) of all injury hospitalisation in Australia from 2006 – 2009 (AIHW: Mc Kenna, 2012). An Australian Institute of Health and Welfare (AIHW) report found accidental falls were more common among women and three times more likely to occur in remote regions compared with major cities. Furthermore, the report established falls were highest among Australians aged 60 years or older (accounting for one-third of hospitalised injury), but were also the most common cause of injury requiring hospitalisation among children aged 5 – 14 (45%) (AIHW: Mc Kenna, 2012).

In 2007-08, the estimated total cost of hospital care for fall-related injuries in Australia was $648.2 million, whilst the associated “lifetime” costs (including pain, suffering, and loss of independence and productivity) exceeded $1 billion (AIHW: Bradley, 2013). Likewise, Canadian estimates exceed $2.8 billion/year, accounting for one-fifth of falls-related deaths in those aged over 65 (PHAC, 2011). Moreover, the number of fall-related injuries worldwide is expected to rise over the coming years along with the ageing population (Hendrie, Hall, Legge, & Arena, 2003).

One of the most commonly identified risk factors for falling and subsequent injury is impaired balance (Nickens, 1985; Rogers, Fernandez, & Bohlken, 2001; Tinetti & Speechley, 1989). The human body is not a rigid structure and requires a controlling system to maintain stability at rest and during movement. Balance is defined as the
ability to maintain the line of gravity (vertical line from the centre of gravity) of a body within its base of support with minimal postural sway (Hrysomallis, 2011; Shumway-Cook, Anson, & Haller, 1988). Postural sway is the movement phenomenon of constant displacement and correction required to maintain balance.

Maintaining balance requires coordination of input from multiple sensory systems including the visual, vestibular and somatosensory systems (Gribble & Hertel, 2004). Balance disturbances, detected by measuring alterations of postural sway, causing impaired neuromuscular function and resultant loss of standing balance and increase incidence in actual falls (Treleaven, et al., 2003; Stokell, et al., 2011), are present in a wide range of orthopaedic, sports, neurological, geriatric or paediatric clinical conditions.

Together, the two phenomena of chronic pain and accidental falls can have a profound impact on the lives of a patient, their families and carers, often leading to a psychologically and socio-economically disadvantaged lifestyle. This impact is expected to dramatically increase in both Australia and the United States as the number of adults over the age of 65 is expected to double by the year 2030 (ABS, 2003; Rogers, et al., 2001).

5. Chronic Neck Pain (CNP), Sensorimotor Disturbances and Balance

Patients with chronic neck pain often describe the associated symptoms of unsteadiness, dizziness, light-headedness, loss of standing balance and a sensation of falling, as well as a history of increased incidence of actual falls (Karlberg, Magnusson, Eva-Maj, Agneta, & Moritz, 1996; Karlberg, Persson, & Magnusson, 1995; Lafond, Champagne, Cadieux, & Descarreaux, 2008; Madeleine, Prietzel,
The presence of these symptoms occurs regardless of whether the pain is idiopathic or trauma-induced (Field, Treleaven, & Jull, 2008). The symptoms have been attributed to altered (increased or decreased) somatosensory afferent input from the cervical spine. The mechanisms involved include altered mechanoreceptor (primarily Type 2) and muscle spindle function, inflammatory mediators, sympathetic nervous system (SNS) activation or central nervous system (CNS) inhibition producing disturbances to the sensorimotor control system required for postural stability, adequate head orientation and eye movement. Altered visual and vestibular input into this control system, caused indirectly by altered cervical mechanoreceptor function, is known to produce further disturbances (Jull, Falla, Treleaven, Hodges, & Vicenzino, 2007; Karlberg, et al., 1995; Kristjansson & Treleaven, 2009; Lafond, et al., 2008; Treleaven, Jull, & LowChoy, 2006; Treleaven, et al., 2008). Figure 1.1 summarises the mechanisms of altered cervical somatosensory input on the sensorimotor control system in neck disorders.

![Figure 1.1](Adapted from (Treleaven, 2008))
A relationship between chronic neck pain and symptoms associated with balance disturbance is further indicated by studies confirming the improvement in standing balance and neck pain following treatment localised to the cervical spine (Bronstein, Brandt, Woollacott, & Nutt, 2004; Heikkilä, Johansson, & Wenngren, 2000; Karlberg, et al., 1996). Furthermore, Poole, Treleaven, and Jull (2008) have demonstrated that neck pain in the elderly contributes to disturbances in balance and gait parameters over and above that which occurs with normal ageing.

6. Factors Influencing Chronic Neck Pain (CNP) and Postural Sway

Studies have consistently demonstrated that anthropometric and demographic measures can directly influence both chronic neck pain and postural sway. Influential anthropometric measures include BMI, weight, foot size and width, height and leg dominance, while the influential demographic measures include gender, age, occupation and levels of and types of physical recreational activities (Ferreira, et al., 2112). In addition, an individual’s history data relating to the number and types of prescribed medication(s) and origin of symptoms are known to relate to both the differing central processing mechanisms and pathways involved in chronic neck pain and its subsequent prognosis and postural sway outcomes (Chien & Sterling, 2010; Scott et al., 2005). However, only a few studies involving balance assessment in CNP sufferers actually record or report on these measures (Sjostrom et al., 2003; Stokell et al., 2011). To evaluate the influence of these factors, to assess the possible presence of confounding factors and facilitate inter-study comparative analysis, future research studies involving balance assessment in CNP sufferers require a standardised protocol of recording participants’ demographic and anthropometric measures.
6.1 Weight / BMI

The prevalence of obesity in Australia has increased 2.5 times in the twenty years from 1980 to 2000 (Cameron et al., 2003; Walls et al., 2009). Finucane et al. (2011) reported that the mean BMI for Australian males and females, are respectively, 27.6 and 26.9 kg/m². General population studies have established the existence of a comorbid relationship between obesity and chronic pain, regardless of age. Hitt, McMillen, Thornton-Neaves, Koch, and Cosby (2007) and McCarthy, Bigal, Katz, Derby, and Lipton (2008), have demonstrated that chronic pain of higher prevalence, severity, frequency and involving multiple locations is noted in individuals in higher BMI categories. In addition, Bigal, Liberman, and Lipton (2006) reported that greater frequency and severity, but not prevalence, of episodic attacks of chronic migraine are associated with higher BMI categories (Bigal, et al., 2006).

Contradictory evidence exists regarding the association between high BMI scores and postural sway. Teasdale et al. (2006), Hue et al. (2007) and Ku, Abu Osman, Yusof, and Wan Abas (2012), have demonstrated that obesity is directly associated with an increase in postural sway during static balance testing. Hue, et al. (2007) proposed that increased BMI results in intrinsic postural instability due to the centre of mass being located more anteriorly over the base of support and the de-sensitisation of the foot mechanoreceptors. However, Cruz-Gómez, Plascencia, Villanueva-Padrón, and Jáuregui-Renaud (2011) found the linear association between increased BMI and postural instability only exists under vision-eliminated conditions.

Other researchers have found the influence of BMI on postural sway is age-dependent, since a high BMI was a significant risk factor for falls among younger adults (< 45
years of age), but a significant protective factors in older adults (> 64 years of age) (Era et al., 1996; Malmivaara, Heliövaara, Knekt, Reunanen, & Aromaa, 1993). Røgind, Lykkegaard, Bliddal, and Danneskiold-Samsøe (2003) demonstrated alterations in the movement strategy (decreased ankle and increased hip-strategies) employed to maintain balance as an individual’s body mass increases. No study describes the relationship between BMI scores and postural sway during dynamic balance tests. Likewise, to date the relationship between BMI and postural sway in the specific clinical population of CNP sufferers has yet to be examined. Further investigations to confirm any relationship between BMI and postural sway in CNP sufferers is warranted.

6.2 Foot Width and Size

No study has investigated the association between foot width and / or size and the presence and / or severity of chronic neck pain. Chiari, Rocchi, and Cappello (2002) have shown that anthropometric measures including foot width directly influence the size and geometry of the base-of-support. Not unsurprisingly, they also found that the foot width and size measures were larger in males compared to females, producing a corresponding larger base-of-support area.

A consistent finding among researchers is that a larger base-of-support area increases balance and reduces postural sway (Alonso et al., 2012; Chiari, et al., 2002; Chou et al., 2009). A significant reduction in computerized force plate measures of lateral body sway (ML direction) have been demonstrated with an associated increased total stance width due to the reduction of angular motion about both the ankles and feet (Alonso, et al., 2012; Day, Steiger, Thompson, & Marsden, 1993). Therefore, it is
not inconceivable that any demonstrated relationship between foot width and/or size and postural sway may solely be mistakenly attributed to gender.

6.3 Height

Regardless of gender, height is recognized as the most influential anthropometric measure affecting balance, since the height of the body’s centre of gravity is shown to be inversely related to postural stability (Alonso, et al., 2012). Relative few balance assessment studies, involving CNP sufferers, have recorded data for body height. Although studies by Michaelson et al. (2003), Karlberg, et al. (1995) and Röijezon, Björklund, and Djupsjöbacka (2011) have recorded anthropometric measures including height, none of these studies reported the influence of height on balance in CNP sufferers. To facilitate comparative analysis between studies, a standard protocol of recording and reporting participants’ height and other anthropometric measures is recommended. Furthermore, relationships between height and balance in CNP sufferers may need to be considered in studies combining male and female gender participants.

6.4 Leg Dominance

Leg dominance has been shown not to influence postural sway measures during a single-foot static balance test (Alonso, Brech, Bourquin, & Greve, 2011; Rigoberto, Toshiyo, & Masaki, 2010). To date the influence of leg dominance on postural sway during bipedal stance balance tests is unknown. However, increased postural sway is reported, especially in the ML direction, when dynamic balance tests are commenced with the non-dominant leg (Rigoberto, et al., 2010), potentially due to the reduced
exposure to initiating gait with that leg (Winter, 1995b). Interpretation of data between similar studies is often further complicated by the non-recording of leg dominance and the actual leg used for the balance tests. A standardised procedure of employing and recording the dominant leg for the commencement of any balance test assessment in CNP sufferers is recommended.

6.5 Gender

Epidemiologic studies have established that CNP is more prevalent, persistent and widespread (experienced in multiple locations), has an associated higher degree of disability and is less likely to be resolved, in women than men (Andersson, Ejlertsson, Leden, & Rosenberg, 1993; Côté, Cassidy, & Carroll, 1998; Côté, et al., 2004; Fejer, et al., 2006; Guez, Hildingsson, Nilsson, & Toolanen, 2002; Hogg-Johnson et al., 2008). Similarly studies including those by Chesterton, Barlas, Foster, Baxter, and Wright (2003), Fillingim, Edwards, and Powell (2000) and Rivest, Côté, Dumas, Sterling, and De Serres (2010), have demonstrated a significant difference between genders in the mean mechanical pain threshold testing (MPPT) scores when repetitively measured, with females showing lower thresholds. This difference is independent of the anatomical measurement site. These researchers concluded that the magnitude of the difference is likely to be at a clinically relevant level and hence may potentially produce biased experimental results. Consequently, caution is required when interpreting MPPT results for mixed groups of men and women.

Several studies have shown that gender does not affect postural sway during static balance testing, even under altered visual and surface conditions (Hageman, Leibowitz, & Blanke, 1995; Maki, Holliday, & Fernie, 1990; Røgind, et al., 2003;
Wolfson, Whipple, Derby, Amerman, & Nashner, 1994). However, to date no study has specifically investigated the effect of gender on postural sway during dynamic (functional) balance testing.

6.6 Age

Studies have consistently demonstrated that age influences both chronic neck pain and postural sway. The prevalence of neck pain has been shown to increase with age to 50-59 years and then gradually decreases, regardless of gender (Andersson, et al., 1993). Furthermore, with increasing age complete resolution of neck pain is less likely to occur, thereby leading to a higher incidence of persistent symptoms (Côté, et al., 2004; Guez, et al., 2002).

Postural sway has been shown to increase with age, potentially due to a decline in the functioning of the visual, vestibular and somatosensory components of the postural control system (Era & Heikkinen, 1985; Gill et al., 2001; Hageman, et al., 1995; Røgind, et al., 2003). Studies by McClenaghan et al. (1996), Williams, McClenaghan, and Dickerson (1997), Maki, Holliday, and Topper (1994) and Piirtola and Era (2006), all suggest that ageing affects the postural sway frequency-domain spectral characteristics predominately in the medio-lateral (ML) direction, and this direction is the best predictor of those individuals at risk of falling. To minimise the impact of age on balance measures, CNP researchers have restricted the age range for subjects to 18 – 45 or 50 years inclusively (Field, et al., 2008; Röijezon, et al., 2011).

Finally, Poole, et al. (2008) have shown that neck pain contributes to disturbances in balance and gait parameters over and above that which occurs with normal ageing. Similarly, Treleaven, Jull, and Lowchoy (2005b) found balance deficits in chronic
neck pain patients with dizziness were not attributed to age. Since age has a known
influence on both CNP and the detection of balance disturbances, clearly resolution of
its influence in CNP sufferers is required and warrants further assessment.

6.7 Prescribed Medications

Treleaven, Jull, et al. (2005b) have demonstrated no difference in balance responses
between study participants who did and didn’t take regular medication. However, in
CNP sufferers, research has shown that balance is influenced by taking narcotic and
other pain relieving or anti-inflammatory medications, or consuming alcohol up to 24
hours prior to testing (Ålund, Larsson, Ledin, Ödkvist, & Möller, 1991; Ferrari &
Sciance Russell, 1999). A need to record all current medication(s) taken and to refrain
from consuming these medication(s) for at least 24 hours prior to assessment of
balance would appear to be a practical option to avoid their potential confounding
effects when testing balance in CNP sufferers.

6.8 Occupation

Occupation does not appear to influence CNP. Hill, Lewis, Papageorgiou, Dziedzic,
and Croft (2004) and Palmer et al. (2001) have demonstrated that employment status
or other psychosocial influences rather than occupational factors, including physical
demands of the workplace, were predictive of persistent neck pain in the general
population. In addition, Haldeman, Carroll, Cassidy, Schubert, and Nygren (2008)
found neck pain to be common in all occupational categories, with only between 11 –
14.1% of surveyed workers reported being limited in their activities because of neck
pain.
No study as yet has assessed the influence of the type of occupation on postural sway. However, prolonged sessional positioning and work activities inducing neuromuscular fatigue, have been shown to result in increased postural sway over time (Singh, Park, Levy, & Jung, 2009). Further research is required to assess if a relationship exists between occupation and postural sway.

6.9 Origin of Symptoms

Scott, Jull, and Sterling (2005) have demonstrated that widespread hypersensitivity as measured by MPTT is a feature of traumatic and not idiopathic CNP. Static balance studies for CNP sufferers, employing CFPs, indicate that the balance disturbances were greater in participants when the neck pain was of traumatic origin (Field, et al., 2008). Clearly, due to the known influence of the origin of symptoms on both postural sway and MPTT measures, it is important that it is recorded in any study involving balance assessment in CNP sufferers.

In concluding, the known influence of the anthropometric, demographic and historical measures of BMI, weight, foot size and width, height, leg dominance, gender, age, occupation, number and types of prescribed medication(s) and origin of symptoms on both CNP and / or postural sway and the potential presence of confounding effects, warrants their inclusion in any experimental design for a research study involving balance assessment in CNP sufferers.

7. Assessment of Chronic Neck Pain (CNP) and Disability

Chronic neck pain is a multidimensional phenomenon consisting of sensory intensity and affective magnitude components. Its relationship to disability is influenced by
physiological, psychological, social and environmental factors and knowledge of this relationship would assist with diagnosis, optimize clinical interventions and enhance future clinical research. Although there is a plethora of literature about the assessment of pain, three main considerations of clinical utility (short, efficient measure producing useful information), validity and reliability determine the suitability of a pain measure in the clinical environment. The three main categories of pain measure are self-report, observational and physiological measures. All have some degree of error and each only provides insight into one aspect of the sufferer’s current pain experience.

Pain intensity forms but one component of the multidimensional pain experience. It must be assessed in conjunction with the affective aspect of pain and pain-related disability (activity limitation) as these additional measures are important in the assessment and on-going monitoring of medical conditions involving balance disturbances and their subsequent management. Researchers including Price, McGrath, Rafii, and Buckingham (1983) and Wewers and Lowe (2007), have verified the validity of self-report measures for sensory intensity and affective magnitude as ratio scale measures for both chronic and experimental pain. On the other hand, Carlsson (1983) warns of an individual’s tendency to bias their estimates of pain and recommends the use of an absolute, rather than a comparative, scale measure in clinical research.

### 7.1 Self-Rating Questionnaires (SRQ)

Self-report measures are considered the “gold-standard” of pain measurement, as they are most consistent with the IASP’s definition of pain (Strong, 1999). In addition,
research has demonstrated an individual’s self-report is the most reliable measure of pain and disability, with health care professionals tending to underestimate severity (Prkachin, Solomon, & Ross, 2007). As chronic pain is a multidimensional phenomenon, self-report measures are rarely employed in isolation. Appropriate selection of a combination of self-report measures must include a description of the pain, individual response to the pain and the impact of the pain on the sufferer’s life. Suitability of these self-report measures for the clinical practice environment is primarily determined by their expense, ease of administration and time efficiency. Caution is required in selecting a number of self-report measures due to a potential cross-over effect between the measures themselves or responder’s fatigue. While the pain experience is individual, some clinical populations display special features, which may be detected by distinctive self-report measures. For CNP sufferers, the Neck Disability (NDI) measure is one such measure. The commonly used self-report measures of pain and disability for CNP sufferers that cover all the different components of their pain experience include:

7.1.1 The Visual Analogue Scale (VAS Pain)

The VAS (Pain) questionnaire has a long history of administration in clinical research and its use is supported by a considerable body of clinometric research. Kamper, (2012); Field, et al. (2008); Karlberg, et al. (1996); Poole, et al. (2008); Scott, et al. (2005) and Treleaven, Jull, and LowChoy (2005a), amongst others, have verified the use of the VAS (Pain) questionnaire specifically in chronic neck pain populations. Regardless of gender, pain perception and rating have been shown to be inversely related to age (Gibson & Helme, 2001). The questionnaire records a “sensory intensity” (or how intense the pain is) component measure of their current (in situ)
pain and is suitable to be used to relate the severity of chronic pain in CNP sufferers with any balance disturbances.

7.1.2 The Visual Analogue Scale (VAS Stress)

The VAS (Affective) questionnaire is used to measure the “affective magnitude” (or how distressing is the pain) component of pain experienced, and consists of feelings of unpleasantness and emotions associated with future implications, termed “secondary affect” (Price, 2000). Researchers have found that the affective component of clinical pain in chronic pain patients is higher due to a perceived degree of threat to health (Price, Harkins, & Baker, 1987). However, the present study aimed to measure the current (in situ) pain-related stress, excluding the “secondary affect”, and selected a VAS (Stress) questionnaire to measure the magnitude of current stress associated with chronic pain in CNP sufferers with any balance disturbances.

7.1.3 The Neck Disability Index (NDI)

The NDI is the most widely used and validated questionnaire for assessing self-rated functional disability in patients with neck pain in both clinical and research settings (Vernon, 2008). This index has limitations as it is a physical disability measure and does not measure change of emotional and / or social functioning, which is common among CNP patients (Jose, 2012). The NDI has an established high test-retest reliability from three weeks to three months in CNP patients (Jose, 2012; Rebbeck & Sterling, 2005), and is moderately correlated ( $r = 0.6 - 0.65$ ) with VAS (Pain and Stress) measures (Fejer & Hartvigsen, 2008; Hermann & Reese, 2001). It has not been used to determine any associated emotional and / or social functional disability level associated with CNP and its relationship with disturbances of balance.
7.1.4 The Short Form Health Survey (SF - 36)

The SF-36 is a measure of functional health and well-being, providing physical and mental health summary measures, with higher scores representing a better health status. The survey has shown high validity and reliability in both the healthy and clinical populations, including neck pain sufferers, and is able to identify coexisting health problems, for example psychological problems often unrecognised by other assessment methods (Ware & Gandek, 1998; Ware Jr, 2000; Ware Jr & Sherbourne, 1992). The SF-36 has similar responsiveness and validity to the NDI neck-specific questionnaire (Stewart, Maher, Refshauge, Bogduk, & Nicholas, 2007). However, caution is required when interpreting results for this measure, since some of the subscales, especially physical function, are prone to “floor and ceiling effects”. This occurs when the measure is insensitive for patients with very high or very low levels of disability in performing physical activities (Davidson, Keating, & Eyres, 2004; Patel, Donegan, & Albert, 2007). A previous study by Hughes, Duncan, Rose, Chandler, and Studenski (1996), incorporating the physical functioning domain of the SF-36, established that the relationship between measures of postural sway and self-rated disability is inconsistent. However, the questionnaire may be a suitable measure for assessing the relationship between health status and balance disturbances.

7.1.5 The Depression Anxiety Stress Scales - 21 (DASS-21)

The role of psychological risk factors, such as stress, distress, anxiety and mood or emotions, in all pain conditions, are factors that play a significant role in the onset of chronic pain, its transition from acute pain and in its continuation (Linton, 2000). Lovibond and Lovibond (1995) have found that the DASS-21, which captures many
of these factors, is useful in clinical situations. This tool captures emotional disturbance associated with a condition with high internal consistency, validity (both construct and convergent), and reliability in differentiating the scales of anxiety, depression and tension or stress, which have a high co-morbidity. Furthermore, the DASS-21 has been demonstrated to be a reliable and valid measure for all three scales in mature adults with chronic pain, especially those aged 50 - 60 (Wood, Nicholas, Blyth, Asghari, & Gibson, 2010). Only one study has employed this measure in a clinical study involving CNP patients (Stewart et al., 2007). The majority of clinical studies utilising the DASS-21 measure relate to chronic low back pain conditions. The questionnaire is a quantitative measure of distress, but it is not a categorical measure of clinical diagnoses. One limitation of the questionnaire is that it only measures participants for distress “over the past week”. Therefore, its suitability for inclusion in clinical studies with chronic conditions, such as CNP sufferers, is unknown due to this limited testing period.

Although an extensive range of self-report measures of pain and disability are commonly used for CNP sufferers, the appropriate combination of these self-report measures to include a description of, and response to the pain and its impact on the sufferer’s life is attained with the VAS (Pain), VAS (Stress), NDI, SF-36 and DASS-21 SRQ measures. This selected combination of self-report measures of pain and disability are also being employed to assess their association with balance in CNP sufferers.
7.2 Mechanical Pain Threshold Testing (MPTT)

Pressure Algometry detects mechanical pain thresholds, which is but one quantitative measure of sensory sensitivity to pain. Decreased mechanical pain detection and tolerance thresholds indicate central nervous system (CNS) sensory mechanical hyperalgesia (hypersensitivity to pain), providing evidence of augmented central pain processing mechanisms, often referred to as “central hyperexcitability”. Researchers have proposed conflicting theories to explain the phenomenon of sensory mechanical hyperalgesia. Chien and Sterling (2010) suggest that the more widespread the hyperalgesia detected (for example, decreased mechanical pain threshold at an asymptomatic remote site), the more profound the changes to the CNS pain processing mechanisms. This theory is supported by Walton, MacDermid, Nielson, Teasell, Reese, et al. (2011) who confirmed that the MPTT measured at a site distal to the injury, and not at the local injured site, is one of the most reliable prognostic indicator in determining the short-term outcome in people with traumatic neck pain. The MPPT results at a site distal to injury are explained by either a “fear-related avoidance” model of a painful stimuli (Walton, MacDermid, Nielson, Teasell, Reese, et al., 2011), or an “anxiety/endocrine function” model (McLean, Clauw, Abelson, & Liberzon, 2005).

Despite contradictory mechanistic explanations for effect, the pressure algometer has high reliability and validity for repeated readings for maximum pressure and rate of force applied when compared with simultaneously recorded force plate readings (Kinser, Sands, & Stone, 2009). Bisset and Evans (2011), Cathcart and Pritchard (2006), Prushansky, Handelzalts, and Pevzner (2007) and Walton, Macdermid, Nielson, Teasell, Chiasson, et al. (2011), have all demonstrated good intra-tester,
inter-tester and test-retest reliability for pressure pain algometry in varying age groups for both healthy and patient participants, even when performed by inexperienced testers. However, a systematic literature review by Stone, Vicenzino, Lim, and Sterling (2013) concluded that due to the high variability of test results leading to heterogeneity of results for both healthy and patient samples, the MPPT in isolation is not an optimal test for either research or clinical practice environments when aiming to detect evidence of central hyperexcitability compared with intramuscular or cutaneous electrical stimulation protocols or nociceptive flexor reflex thresholds.

As a quantitative measure, pressure algometry is largely considered an objective measure of the mechanical pain threshold. Yet, as pressure algometry relies solely on participant’s feedback to report pain, and subconsciously may be influenced by examiner bias during the actual testing, it is in reality a subjective measure. Although the latter influence may be overcome by having a blinded experimental protocol, caution is still required when interpreting any clinical results using pressure algometry (Ylinen, Nykänen, Kautiainen, & Häkkinen, 2007). Another limitation with pressure algometry is that it is unable to identify the site or precise mechanism underlying the abnormalities in central nociceptive processing, and thus unable to indicate specific treatment interventions (Sterling, 2011). Recent research findings indicate that a number of genes play a critical role in determining an individual’s pain sensitivity and susceptibility to chronic pain (Young, Lariviere, & Belfer, 2012), but as yet no study has investigated the association between these genes and mechanical pain threshold test measures. Notwithstanding the limitations and contradictory mechanistic explanations of pressure algometry, it is an inexpensive, less invasive, easy to conduct and time efficient technique for measuring sensory sensitivity to pain, offering an
indication of central hyperexcitability, suitable for use in the clinical practice environment.

Other researchers have employed synthetic monofilaments (or von Frey filaments) for mechanical pain sensory threshold testing. However, due to their associated high cost and the potential flaws in testing protocols highlighted by Fruhstorfer, Gross, and Selbmann (2001) and rated as a “tin standard” by Bove (2006), this method of mechanical pain sensory threshold testing does not appear to be indicated as a clinical or research tool.

7.3 Skin Conductance Response (SCR)

Skin conductance (also known as galvanic skin response) is often used as an indication of psychological (emotional) or physiological arousal, and is a measure of the electrical conductance of the skin which varies according to its moisture level due to SNS influence on the sweat glands. Accordingly, skin conductance can be used as a measure of sympathetic responses to painful stimuli. However, external factors, including temperature and humidity, are known to influence skin conductance measurements leading to inconsistent results, and are rarely controlled in the clinical environment or during clinical research studies. In addition, poor reliability of these measurements when using electrical stimuli has been demonstrated by Breimhorst et al. (2011). These limitations restrict the use of this measure as a method of pain assessment in the clinical practice environment.

In conclusion, studies have demonstrated the validity, reliability and responsiveness of the SRQ, particularly the VAS (Pain), VAS (Stress), NDI, SF-36 and DASS-21, and MPTT measures in assessing pain and disability in CNP sufferers (Stewart,
Other possible measures for the assessment of pain, like SCR, have demonstrated to be of limited, if any, value in the clinical practice environment. However, the relationships of SRQ and MPTT measures to those of balance disturbances in CNP sufferers are yet to be investigated.

8. Assessment of Balance in Chronic Neck Pain (CNP) Sufferers

Balance is often assessed as the amount of postural sway of the body during both static and dynamic (functional) conditions. Static balance is defined as the ability to maintain the line of gravity within the body’s base of support with minimal movement whilst having at least one foot fixed on the ground. Dynamic balance is defined as the ability to maintain or regain balance during weight shifting or voluntary movements. Postural sway can be measured by the amount of total excursion of the body’s centre of gravity (CoG), often termed the centre of mass (CoM), relative to the base of support over time (Wang, Skubic, Abbott, & Keller, 2010). A valid, reliable objective clinical assessment for balance is currently not available. However, the quantification of postural sway may give an indication of the individual’s balance performance (Rogind, Simonsen, Era, & Bliddal, 2003).

8.1 Clinical Balance Tests

Numerous static and dynamic clinical balance tests have been used to quantitatively assess postural sway in the healthy and CNP sufferers, including the “Single Leg Stance” (Bohannon, 1997; Bohannon, Larkin, Cook, Gear, & Singer, 1984); “Step Test” (Hill, 1996); Fukuda Stepping Test (Honaker, Boismier, Shepard, & Shepard, 2009); Singleton Test (Herdman, 2007); “Timed 10 m Walk” (Bohannon, 1997); and
the “Star Excursion Test” (Bressel, Yonker, Kras, & Heath, 2007). These clinical tests are commonly employed in clinical practice, and rely solely on the visual assessment of balance by the tester. Many have good intra-tester reliability, but low inter-tester reliability, and are subject to tester bias (Stokell, Yu, Williams, & Treleaven, 2011). The value of these tests is also limited by their low sensitivity to changes of balance (Clark et al., 2010). Furthermore, some static clinical balance tests may fail to discriminate small differences in sway patterns to detect deficiencies of postural sway (Wikstrom, Tillman, Smith, & Borsa, 2005). Functional clinical tests are often only a “moment-in-time” assessment and do not provide a “continuous” measure of dynamic balance. The challenge among clinicians regarding accurate assessment of balance and the need for a standardised measurement system was confirmed by a recent study among Canadian physiotherapists establishing that seventy-nine per cent of respondents indicated a need to improve their clinical assessment of balance (Sibley, Straus, Inness, Salbach, & Jaglal, 2011, 2013).

8.2 Computerised Force Plates (CFP)

Posturography is a quantitative method for assessing human upright balance function (Nashner & Peters, 1990). It uses the quantitative measurement of postural sway and detects alteration in sway patterns in the healthy and symptomatic individuals. Computerised posturography monitors the centre of pressure (CoP) motion over a specified period of time as recorded by a laboratory-grade computerised force plate (CFP). This is the most prevalent laboratory-based test for measuring postural sway and is accepted as the “gold-standard” reference (Clark, et al., 2010; Haas & Burden, 2000). A study by Lin, Seol, Nussbaum, and Madigan (2008) has clearly demonstrated the high within-day day and medium between-day reliabilities for CoP-
based postural sway measures, regardless of age. Although, it is acknowledged that the displacement of the CoP is not identical to the displacement of the centre of gravity (CoG) (Winter, 1995a), if the sampling period is adequate, the mean position of the CoP adequately reflects the mean position of the CoG of the body (Goldie, Bach, & Evans, 1989).

Computerised posturography studies, employing a computerised force plate, have identified alterations in postural sway in CNP sufferers under altered visual and surface conditions (Field, et al., 2008; Gill, et al., 2001; Karlberg, et al., 1995; Lafond, et al., 2008; Michaelson, et al., 2003; Sjöström et al., 2003; Stokell, et al., 2011; Treleaven, 2011; Treleaven, Clamaron-Cheers, & Jull, 2011; Treleaven, et al., 2003). Field et al., (2008) indicated that the balance disturbances were greater in participants when the neck pain was trauma related, whilst Treleaven et al., (2005) found them to be greater in those who reported symptoms of balance disturbance. These studies, as with the clinical balance tests described in section 8.1, were limited to static or functional clinical tests that did not provide a “continuous” measure of dynamic balance.

Studies using CFP balance test protocols have established validity and reliability in detecting balance disturbances, in the anterior-posterior (AP) or ML direction, in patients with chronic neck pain of different aetiology, such as whiplash-related or insidious (Alund, Ledin, Odkvist, & Larsson, 1993; Field, et al., 2008; Karlberg, et al., 1996; Karlberg, et al., 1995; Madeleine, et al., 2004; Michaelson, et al., 2003; Poole, et al., 2008; Treleaven, Jull, et al., 2005b). A systematic literature review by Ruhe, et al. (2011) and findings by Cherng, et al. (2003), Vuillerme and Pinsault (2009), Goto, et al. (2011), Wada, et al. (2001), Field, et al. (2008) and Madeleine, et
al. (2004) demonstrated that the AP direction was the most significant direction in
detecting increases of postural sway in healthy individuals and CNP sufferers.
Furthermore, the systematic literature reviews by Ruhe, Fejer, and Walker (2010) and
Ruhe, Fejer, and Walker (2011) confirmed patients with neck pain, regardless of its
origin, exhibited greater postural instability (measured by CFP’s CoP excursions) than
healthy controls for varied bipedal static balance task testing under differing
conditions. However, the validity and reliability in detecting balance disturbances
during a “continuous” measure of dynamic balance in CNP sufferers is yet to be
established.

Moore, Rushmer, Windus, and Nashner (1988) and McClenaghan, et al. (1996) have
found that AP directional postural stability is maintained primarily by musculature
associated with the ankle, whilst the ML directional stability occurs at the hip region.
Thus, it is necessary for any method evaluating balance and its associated
disturbances to provide valid and reliable measures in both, and not just one, of these
directions to fully assess all strategies employed in maintaining postural stability.
However, when testing directional postural stability, the vertical direction (time-
domain) measures have been shown to have the highest reliability in discriminating
between the increasing states of unsteadiness for a range of stance balance tests
(Goldie, et al., 1989). Consequently, it could be inferred that when comparing
dynamic-based to stance-based balance activities, with increasing levels of
unsteadiness requiring a greater degree of effort to maintain postural stability, the
vertical direction measures may offer greater insight when evaluating balance, but to
date this has not been investigated. Therefore, for the more challenging static-based
and all dynamic-based balance tests valid tri-axial direction measures of postural
sway are required to fully assess all strategies employed in maintaining postural stability.

CFP balance tests that are not performed regularly require learning and, thus, are cognitive demand tasks. Execution of these types of tasks adversely influences postural sway, with a resultant increased postural sway area, especially in the elderly (Huxhold, Li, Schmiedek, & Lindenberger, 2006; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997; Teasdale & Simoneau, 2001). Knowledge of the degree of difficulty and the type of challenge in a balance test is required when interpreting and comparing postural sway results from a diversity of static and dynamic balance tests.

The laboratory-grade CFP devices are expensive, lack portability and associated accessibility, rendering them of restricted use in the clinical practice environment. However, as the “gold-standard” reference, CFP should be used in research studies relating to balance disturbances in CNP sufferers to validate other potential but more accessible balance devices capable of valid tri-axial assessment of postural sway during both static and dynamic balance tests.

### 8.3 Global Positioning System (GPS) Devices

Global Positioning System (GPS) technology has been shown to be a useful tool to augment our understanding of physical activity by providing the context (location) of the activity and, used together with Geographical Information Systems (GIS), can provide insight into how people interact with the outdoors environment. However, no clinical population studies have shown that GPS alone is a reliable and valid measure of physical activity (Maddison & Mhurchu, 2009). In addition, the initial equipment purchase cost and associated burden of wearing such a device (usually within a
wearable vest) may have contributed to their lack of adoption in the clinical practice environment.

### 8.4 Other Wearable Balance Devices

Other researchers have identified the need for an accurate, inexpensive and easily accessible technique for quantitatively measuring postural sway during both static and continuous dynamic balance tests in the clinical environment. They have proposed devices such as: the Nintendo Wii Balanced Board (Clark, et al., 2010); Balance Performance Monitor (BPM) (Haas & Burden, 2000); Wireless Orientation Sensors (Jasiewicz, Treleaven, Condie, & Jull, 2007); Webcams (Wang, et al., 2010); Swaymeter (Sturnieks, Arnold, & Lord, 2011); SwayStar (Held-Ziolkowska et al., 2000; Sjöström, et al., 2003); Vibrotactile Sensory Feedback (Lee, Kim, Chen, & Sienko, 2012); Stabilometer (Davlin, 2004); and the Biodex Balance System (Platzer, Raschner, & Patterson, 2009) as balance assessment systems. However, only the Nintendo Wii Balanced Board, BPM and webcam devices have criterion validity having been measured against a laboratory-grade CFP (Clark, et al., 2010; Haas & Burden, 2000; Wang, et al., 2010). But these latter studies displayed limitations by only assessing static balance and lacking portability, as their assessment systems require interface with a computer system. Moreover, these two balance assessment tools are further limited by measuring postural sway in only two of the three axial directions.
8.5 Smart Phones (SP)

The SP market is rapidly expanding with current users exceeding one billion worldwide (Ibtimes, 2012). Research has indicated that SP sensors are capable of monitoring blood pressure, heart rate and body temperature, inferring metabolic energy expenditure, measuring various parameters of gait, recognising activities of daily living, and through wireless internet connections, managing healthcare information (Atallah, Lo, King, & Yang, 2010; Kavanagh & Menz, 2008; Rigoberto, et al., 2010). The latest generations of SPs and Mobile Computing Platforms contain an embedded accelerometer sensor which detects orientation and position. A commercially available application (App) now allows this information to be analysed tri-axially, quantified and stored, thus enabling this device to become a wearable accelerometer (WA). The limitations of the Nintendo Wii Balanced Board and Balance Performance Monitor devices are potentially overcome by the SP, as it has the capability to measure postural sway in all three axial directions and is portable.

Therefore, use of the SP could potentially provide repeated or continuous measures of postural sway during multiple everyday stationary and functional tasks (including activities such as running), making it a valuable clinical assessment and feedback tool of balance disturbance. To date, no study has quantitatively measured postural sway during static and dynamic balance testing or during activities of daily living using the SP or assessed its criterion validity against a laboratory-grade CFP in the AP, ML or vertical directions and using time- or frequency-domain measures.
9. Frequency-Domain Spectral Measures

The traditional time-domain measures of balance from a CFP do not take into account the changing dynamic properties of the postural controlling system (McClenaghan, et al., 1996). However, studies have shown that frequency-domain measures (spectral characteristics associated with postural sway) of balance, including Fast Fourier Transform (FFT) processing, do produce valid and reliable “biomarkers” in the detection of minor changes (Cherng, Lee, & Su, 2003) and the early deterioration of balance across all age groups (Williams, et al., 1997).

The FFT Mean frequency is a frequency-domain measure of central tendency and is often defined as the centroid of the spectrum (McClenaghan, et al., 1996; Vuillerme & Pinsault, 2009). Earlier studies by McClenaghan, et al. (1996) and Cherng, et al. (2003), assuming a normal distribution of frequency, found the FFT Mean frequency is the most valid frequency spectral measure of postural sway in the AP, ML and vertical directions. A systematic literature review by Ruhe, et al. (2011) stated that there was enough consistency in the reviewed studies’ results (involving frequency-domain measures analysis) to show that patients suffering from chronic neck pain exhibit an increase in postural (COP) sway compared to healthy individuals, especially in the AP direction. This finding is also supported by Cherng, et al. (2003) in children and young adult populations, and by Vuillerme and Pinsault (2009) in an experimental neck pain population. Likewise, Goto, Kabeya, Kushiro, Ttsutsumi, and Hayashi (2011) and Wada, Sunaga, and Nagai (2001), whilst assessing the influence of anxiety on postural stability using frequency spectrum analysis in different populations, detected greater postural instability in the AP direction. Field, et al. (2008) and Madeleine, et al. (2004) both found that the AP direction was more
significant than the ML direction in detecting increases of postural sway in CNP sufferers.

However, in contrast, McClenaghan, et al. (1996) found that the most significant difference in central tendency spectral measures of postural sway between young adult and elderly participants without CNP was in the ML direction. Maki, et al. (1994) also demonstrated that changes in frequency spectral measures in the ML direction were the best predictor of individuals at risk of falling. Therefore, selection of the most valid direction for FFT Mean frequency analysis might be age-dependent.

The vertical direction frequency-domain measures of postural sway are known to be less sensitive in detecting changes in the vertical redistribution of the body’s CoM compared to the equivalent time-domain measures and, consequently, are often ignored during results analysis of research data (Rosker, Markovic, & Sarabon, 2011).

Several researchers report finding that for CNP sufferers, frequency spectral analysis undertaken for the most reliable axial direction in detecting postural sway disturbances varies according to the actual balance test performed, the applied visual and surface conditions for that balance test and according to the aetiology of the patient’s pathology (Field, et al., 2008; Treleaven, Murison, Jull, LowChoy, & Brauer, 2005).

Several CFP clinical studies have reported that the spectral measure of root mean square (RMS) is the most reliable in detecting alterations of postural sway in clinical populations (Field, et al., 2008; Mientjes & Frank, 1999; Poole, et al., 2008). Furthermore, researchers have demonstrated that the use of RMS frequency spectral measure in isolation during more challenging balance tests could lead to a Type 2 error.
(false negative) highlighting the importance of selecting an adequate combination of measures for postural sway analysis to detect all the altered strategies employed in maintaining balance (Dault, Geurts, Mulder, & Duysens, 2001; Field, et al., 2008).

As most activities of daily living involve human movement at a low frequency, Bartlett (2007) recommends that the highest frequency of interest in the movement must be included in analysis of data. Similarly, McClenaghan, et al. (1996) suggests to gain an understanding of the rhythmical patterns associated with a specific activity, and thus an better appreciation of the complexity of the postural control system, measures of spectral dispersion should be also be examined. To date no research study has either recorded and / or reported analysis of FFT maximum frequency or standard deviation (SD) frequency-domain measures of dynamic balance. Comparing these measures, using both the CFP and SP, could provide additional information relating to the detection of important, but not easily identifiable, changes in the sensorimotor control system underlying balance.

10. Relationships between Postural Sway, Self-Rating Questionnaires (SRQ) and Mechanical Pain Threshold Testing (MPTT) Measures

10.1 Postural Sway and Self-Rating Questionnaires (SRQ) Measures

Human upright stance is known to be modulated by emotion, cognitive traits and tasks (Carli, Cavallaro, Rendo, & Santarcangelo, 2007). Several researchers have concluded that postural sway in quiet stance includes slow (rambling) and fast (trembling) components (Zatsiorsky & Duarte, 1999, 2000). The slow component is attributed to the sensory information transmission and central processing when estimating the location and movement of the CoM (Kiemel, Oie, & Jeka, 2006).
clinical study of CNP patients, assessed by the self-rating questionnaires, including VAS (Pain), NDI and SF-36, found that an increase in magnitude of the slow component of sway is associated with poorer physical functioning and severity of sensory symptoms (Röijezon, et al., 2011). The study concluded that the increased postural sway reflects impairment and not a functional adaptation in CNP patients. However, these authors cannot eliminate the possibility of functional adaptation since the study’s participants were not measure prior to the onset of their CNP

Owen, Leadbetter, and Yardley (1998) have reported no correlation between postural instability and anxious personality (i.e. trait anxiety construct), whilst Ohno, Wada, Saitoh, Sunaga, and Nagai (2004) found only the state anxiety construct related to frequency-domain measures of postural sway. Induced anxiety is known to primarily affect the postural sway in the AP direction by influencing the interactions of visual inputs with the vestibular and somatosensory inputs in the postural control system in healthy participants during upright stance (Bolmont, Gangloff, Vouriot, & Perrin, 2002; Goto, et al., 2011; Wada, et al., 2001). Maki and McIlroy (1996) observed that elevated levels of anxiety cause a forward shift of the centre of gravity causing the body to lean forward, thus explaining the alteration of postural sway in the AP direction. In contrast, a FFT analysis study revealed anticipatory anxiety in healthy participants amplified postural sway regardless of the visual input and concluded vestibular inputs to the CNS had the greatest influence on postural sway (Ishida, Saitoh, Wada, & Nagai, 2010). Furthermore, in whiplash associated disorders (WAD) CNP patients, balance disturbances were found not to be attributed to anxiety, as measured by the State Trait Anxiety Inventory – Short Form 22 (Treleaven, Jull, et al., 2005b). These researchers concluded that anxiety is unlikely to contribute to the primary cause of balance disturbances of abnormal afferent input from the cervical
spine (either nociceptive or proprioceptive in nature). The conflicting clinical studies in relation to the role of state anxiety indicate the need for additional research to clearly define the roles of visual, vestibular and somatosensory inputs into the postural control during varying levels of state anxiety in CNP sufferers.

Regardless of the underlying physiological mechanisms, further evidence confirming the influence of anxiety on postural sway reveals that during static balance testing the decreased postural control is due to an increase in postural sway or postural stiffness in participants experiencing “Fear of Falling” (Adkin, Frank, Carpenter, & Peysar, 2002; Carpenter, Frank, Silcher, & Peysar, 2001; Delbaere, Close, Brodaty, Sachdev, & Lord, 2010; Maki, Holliday, & Topper, 1991; Tinetti, Richman, & Powell, 1990). However, during dynamic balance testing in normal walking, no signs of decreased postural control were recorded, but a lower gait velocity was adapted to optimise balance by these participants (Reelick, Van Iersel, Kessels, & Rikkert, 2009). To date, it has been beyond the scope of research studies to differentiate between state anxiety and “Fear of Falling” influences on postural sway.

Only a few studies (Field, et al., 2008; Poole, et al., 2008; Treleaven, Jull, et al., 2005b) have assessed the perceived levels of pain and disability in CNP sufferers and their influence on postural sway, measured by the magnitude of CoP excursions. These authors found no significant relationship between postural sway and the level of perceived pain and disability measured by VAS (Pain), NDI and either state or trait anxiety severity levels. Insufficient data exists to suggest a relationship between pain duration and the magnitude of CoP excursions of postural sway. The low pain intensities reported at the time of testing may explain why no significant between-test-groups difference was identified (Ruhe, et al., 2011). An associated study
(Treleaven, Jull, et al., 2005a) found no correlation between the “smooth pursuit neck torsion test” (a measure of neck afferent influence on eye movement control, thus a contributor to the postural control system) and the self-rating levels of pain or disability as measured by VAS (Pain), NDI and either state or trait anxiety constructs. On the contrary, an experimental study (although it does not replicate potential long term nociceptor adaptation by the CNS) found participants with severe induced pain exhibited significantly increased postural sway compared to healthy controls (Vuillerme & Pinsault, 2009). Further studies are warranted to assess the relationship between self-rating of pain, disability and postural sway before any definitive conclusions can be made.

10.2 Self-Rating Questionnaires (SRQ) and Mechanical Pain Threshold Testing (MPTT) Measures

The presence of local sensory mechanical hyperalgesia often found in CNP sufferers highlights the possible influence of “central hyperexcitability” on the physical functioning of these individuals. Petzke, Gracely, Park, Ambrose, and Clauw (2003) confirm that increased pain sensitivity (both sensory and affective) is not a response bias to psychological factors but is correlated with “central hyperexcitability”. Clinical studies have produced contradictory findings when assessing the relationship between self-rating pain, disability and MPTT measures. Researchers have found pressure algometry measures demonstrate good criterion validity when correlated with self-rating pain and disability measures assessed by the VAS (Pain), VAS (Stress) and NDI questionaries (Imamura et al., 2008; Wlodyka-Demaille et al., 2002; Ylinen, 2007; Ylinen, et al., 2007). Goolkasian, Wheeler, and Gretz (2002) have reported similar results utilising the Neck Pain and Disability Scale (NPAD)
questionnaire. Studies involving CNP patients of WAD origin have similarly been found to show a moderate correlation between SRQ & MPTT measures. The magnitude in males is greater but only for the symptomatic cervical spine site (Rivest, et al., 2010; Sterling & Kenardy, 2008). Furthermore, in a similar clinical population, a moderate correlation between NDI scores and MPTT scores was reported, suggestive of a relationship between the levels of self-rating disability and sensory hypersensitivity, but independent of state anxiety measured by the Spielberger State Anxiety Inventory (Scott, et al., 2005). In contrast to this, Laursen, Bajaj, Olesen, Delmar, and Arendt-Nielsen (2005) found no correlation between VAS (Pain) and MPTT measures. Their results were supported by Kamper, Maher, Hush, Pedler, and Sterling (2011) who established only a weak correlation between self-rating of pain intensity and MPTT scores in patients with CNP of WAD origin. Kamper, et al. (2011) concluded that these scores were poor indicators of peripheral or central sensitivity.

Possible explanations for these contradictory clinical study results are inter-related and multifactorial. Pain intensity as assessed by the VAS (Pain) questionnaire provides a multidimensional composite measure of the patient's subjective experience of pain, not just a measure of pain intensity per se (Kowalski, Lund, & Lundeberg, 2002). Prushansky, et al. (2007) highlighted that the VAS (Pain) score demonstrated lower intra-tester reproducibility in patients with neck pain of WAD origin and that this test should be employed only in patients whose initial assessment score exceeds four (4/10). Clinical studies by Sterling, Hodkinson, Pettiford, Souvlis, and Curatolo (2008) and Chien and Sterling (2010), utilising the VAS (Pain) and NDI questionnaires found that thermal, but not pressure, pain thresholds were moderately correlated with perceived pain and disability in CNP patients only of WAD origin. Lastly, researchers
have found that MPTT at a site distal to injury (Tibialis Anterior) and initial pain intensity measured by VAS (Pain) were the main predictors for short-term NDI scores for between 1 to 3 months following onset of symptoms (Walton, MacDermid, Nielson, Teasell, Reese, et al., 2011).

Only two previous clinical studies have demonstrated a relationship between quality of life and pressure threshold measures, but these studies reported conflicting results. Imamura, et al. (2008) demonstrated significant correlations between all SF-36 sub-scales and MPTT measures, except for those of “role-emotional problems” and “general health”. They concluded that lower MPTT values were correlated with higher pain intensity, higher disability and poorer quality of life. In contrast, Laursen, et al. (2005) found no correlation between the MPTT and any of the SF-36 sub-scales for CNP patients, and concluded there was no relationship between pressure hyperalgesia and quality of life. However, caution is required when interpreting the findings of this latter study, due to a small sample size ($n = 10$) and all participants being females.

Psychological distress and anxiety influence pain threshold responses in patients with musculoskeletal pain (Rhudy & Meagher, 2000). Moore, Eccleston, and Keogh (2012), employing five anxiety questionnaires, including the DASS - 21, determined that age and gender did not influence the relationship between either trait or state anxiety constructs and pressure pain thresholds scores.

Obesity has been shown to be directly associated with greater pain-related disability, increased rates of depression and reduced quality of life for physical function in the absence of other chronic medical conditions (Doll, Petersen, & Stewart-Brown, 2012;
Marcus, 2004; McCarthy, et al., 2008). However, a study by Marcus (2004) reported anxiety scores to be independent of an individual’s weight category. Consequently, the relationship between self-rated questionnaires & MPTT measures may be influenced by BMI.

**10.3 Postural Sway and Mechanical Pain Threshold Testing (MPTT) Measures**

No study has assessed the relationship between postural sway and MPTT measures in CNP sufferers. Knowledge of this relationship may provide additional understanding of the mechanisms underlying the disturbances to the sensorimotor control system required for postural stability and potentially improve related treatment interventions in CNP sufferers, and therefore warrants investigation.

In summary, knowledge of the relationships between the postural sway, SRQ and MPTT measures could enhance our understanding of sensorimotor control system disturbances affecting balance, improve related treatment interventions and thereby reduce the associated socio-economic burden for CNP sufferers.

**11. Conclusions**

Clearly, there is a need for an accurate, inexpensive, easy to conduct, time efficient and easily accessible technique, for quantitatively measuring postural sway during both static and continuous dynamic balance tests in the clinical environment. If valid, the SP offers a potential tool for on-going monitoring of postural sway and the immediate assessment and feedback of related treatment interventions, leading to possible improved rehabilitation outcomes for patients experiencing balance
disturbances. In turn, these benefits could result in a reduction in the likelihood of falls-related injuries and provide a measure of general “well-being” (both physical and behavioural). To date, no study has quantitatively measured postural sway during static and dynamic balance testing or activities of daily living using the SP or assessed its criterion validity against a laboratory-grade CFP.

The literature indicates that a number of anthropometric, demographic and historical measures influence the relationship between CNP and postural sway. There is conflicting evidence for the relationship between the measures of self-ratings of pain and disability (using SRQs) and postural sway, measured by a CFP, in both the healthy and CNP sufferers. Furthermore, contradictory evidence also exists for the relationship between the measures for the sensory and affective components of chronic pain, assessed by self-ratings of pain and disability (using SRQs) and MPTT in CNP sufferers. To date, no study has assessed the relationship between MPTT and postural sway measures in CNP sufferers. Knowledge of the relationships between the postural sway, SRQ and MPTT measures could enhance our understanding of the disturbances to the sensorimotor control system required for postural stability, improve related treatment interventions and reduce the associated the socio-economic burden for CNP sufferers.

12. Research Questions

Two main research questions arise from the literature and warrant further study:

1. “Are SP’s measures of postural sway, during both static & dynamic balance tests, valid relative to those from a CFP in CNP sufferers?”
2. “What are the relationships between the different clinical measures of postural sway, self-ratings of pain, disability and MPTT in CNP sufferers?”

13. Aims and Objectives of the Study

The primary aim of the study was to assess the validity of the SP’s simultaneously recorded measures of postural sway (tri-axially) during both static and dynamic balance tests compared to those of the known “gold-standard” reference of a laboratory-grade CFP in participants with and without CNP, following frequency-domain measures analysis, including Fast Fourier Transforms (FFT).

The second aim of the study was to examine the relationships between the measures of postural sway, self-ratings of pain, disability and MPTT in participants with and without CNP.

The study’s objectives were to facilitate the assessment and monitoring of balance in the clinical practice environment and to identify the influence of the sensory and affective components of chronic pain on postural sway in sufferers with CNP. If achieved, these objectives have implications for the future treatment and management of CNP sufferers.
CHAPTER 2

METHODS

1. Overview

The chapter outlines the methodology employed for the study, a description of the participants and measures utilised including instrumentation, procedures, data processing and statistical analyses.

2. Background

This single, cross-sectional and within-participant study was performed at the Faculty of Health, University of Canberra. The University of Canberra Committee for Ethics in Human Research approved the study (Project Number 11-106). Participants were neither paid nor offered any incentives to participate in the study.

After reading the Participant Information Form (Appendix 1) and having the opportunity to ask the researcher questions related to the study, participants agreeing to take part in the study, completed and signed the University of Canberra Informed Consent Form (Appendix 2). A Personal Information Data Form (Appendix 3) was then completed prior to commencing the testing protocol.
3. Participants

Twenty-five participants with chronic neck pain and twenty-five healthy control participants were included in the study (Appendix 4). The participant number for each test group \((n=25)\) was chosen because it was consistent with participant populations in related studies (Poole, et al., 2008; Röijezon, et al., 2011; Stokell, et al., 2011; Yu, Stokell, & Treleaven, 2011) having adequate statistical power to detect differences in the clinical group.

The control and chronic neck pain participants were recruited by forwarding the Participants Recruitment Form (Appendices 5 & 6) to ACT Registered Medical Practitioners, ACT Registered Physiotherapists and the members of the ACT Plaintiff Lawyers Association, who were asked to then forward the form onto appropriate clients. Additional control participants were recruited by distributing the Participants Recruitment Form (Appendix 5) within the University of Canberra and the wider Canberra communities.

All participants were required to be over the age of 18 years to legally provide written informed consent for participation in the study.

Participants’ appointment time for testing was confirmed using the Participant Appointment Form (Appendix 7), at which time the participants were advised that due to a possible influence on their balance to refrain from taking narcotic and other pain relieving or anti-inflammatory medications, or from consuming alcohol, for at least 24 hours prior to testing (Ålund, et al., 1991; Ferrari & Sciance Russell, 1999). Postural control tasks, especially complex ones, have shown to be adversely affected during the following morning hours in sleep-deprived subjects (Schlesinger, Redfern, Dahl,
Auvinen et al. (2010) have reported that insufficient sleep quantity or quality was an independent risk factor for neck pain among females. Accordingly, the participants were also instructed to acquire a normal night’s sleep the night before the day of testing.

Control participants were eligible for participation if they were currently not experiencing any neck or shoulder region pain or discomfort, headaches or dizziness and had no previous history of any of these symptoms either regularly recurring or having lasted longer than a month, during the past decade.

The inclusion criteria for the chronic neck pain participants were that the pain must be current, located in the neck (with or without radiation) and confirmed by the participants on a body chart drawing. For the purpose of the study, the neck was defined as the area bounded by the following anatomical landmarks; the occiput, the spinous process of the third thoracic vertebra and the superio-medial borders of the scapulae. The defined neck area is illustrated as the shaded area in Figure 2.1
Furthermore, the pain for the chronic neck pain participants had to be of at least 3 months duration, with a Visual Analogue Scale (VAS Pain) (Huskisson, 1974) score greater than 1 (0-10) and a score greater than 10 (0-100) on the Neck Disability Index (NDI) (Vernon, 2008; Vernon & Mior, 1991). The inclusion criteria met the IASP definition of chronic pain, being “pain that has persisted beyond the normal healing time of injured tissue, that being a period of time longer than three months” (Merskey & Bogduk, 1994).

Participants were excluded from both groups, if they had reported any history of a medical condition or had been prescribed medication that could adversely influence balance. Additional exclusion criteria included: a history of rheumatic or neurological disease(s); unexplained loss of consciousness within the past 12 months; identified vestibular pathology, major visual or hearing deficits; Type 1 or 2 diabetes; uncontrolled abnormal blood pressure; diagnosed psychiatric disorder; fracture, dislocation or surgery to the shoulder girdle or spinal column; or experienced any major joint or nerve injury (especially involving the lower limb) currently restricting their activities of daily living.

The decision on the participants’ inclusion or exclusion in the study was determined after a review of the completed demographic and history data form, body chart and the completed series of questionnaires at the time of testing.

To minimise the effect of age on balance measures, similar studies have restricted the age range for subjects to 18 – 45 or 50 years inclusively (Field, et al., 2008; Röijezon, et al., 2011). However, a goal of the current study was to assess the suitability of wearable accelerometers in measuring balance disturbances across the population.
Consequently, no restriction on the upper limit of the age range for participants was considered. The test groups were then age - and sex - matched.

At the conclusion of testing, the participants were given the University of Canberra Independent Complaints Contact (Appendix 8) and the “Thank You for Participating” Letter (Appendix 9).

4. Measures

4.1. Demographic / Historical Data and Body Chart

On the day of testing all participants were asked to complete the Demographic and History Data Forms (Appendix 10). The Demographic Form recorded the subject’s age (in years), gender, occupation and basis of referral to the study. The History Data Form detailed the participant’s duration of neck pain in years, origin of the onset of symptoms (traumatic or insidious (non-traumatic)), list and number of current prescribed medications, and the possible history of the medical conditions which would lead to the participant’s exclusion from the study as previously outlined.

In addition, the chronic neck pain participants were asked to complete a body chart drawing (Appendix 11) by marking the site “where you are experiencing pain or other symptoms right now”.

4.2. Self-Rated Questionnaires (SRQ)

All participants were asked to complete a series of five self-rated questionnaires on the day of testing (Appendices 12 – 16). The questionnaires included:
1. *The Visual Analogue Scale (VAS Pain)* questionnaire that records a “sensory intensity” (or how severe is the pain) component measure of their current (*in situ*) pain. The participants were asked to rate their “pain intensity right now” on a scale where 0 corresponds to “no pain at all” and 10 to “worst imaginable pain” (Huskisson, 1974). Greater scores indicate a greater perceived level of the severity of pain.

2. *The Visual Analogue Scale (VAS Stress)* questionnaire was used to measure the pain-related stress component of their current (*in situ*) pain. The participants were asked to rate “how stressed by their pain do they feel right now” on a scale where 0 corresponds to “not stressed at all” and 10 to “extremely stressed”. Greater scores indicate a greater level of the pain-related-stress component of pain.

3. *The Neck Disability Index (NDI)* (Vernon & Mior, 1991), questionnaire that was used to determine the associated functional disability level associated with the neck pain. Greater scores indicate greater disability.

4. *The Short Form Health Survey (SF - 36)* (Ware Jr & Sherbourne, 1992), questionnaire that was employed as a measure of “general health and well-being” (Appendix 17). Higher scores represent better health status. This questionnaire only measures participants for distress “over the past four weeks”.

5. *The Depression Anxiety Stress Scales – 21 (DASS - 21)* (Lovibond & Lovibond, 1995), questionnaire employed as a quantitative measure of distress using sub-scales for depression, anxiety and stress and is not a
categorical measure of clinical diagnosis. This questionnaire only measures participants for distress “over the past week”. The higher the recorded scores the greater the severity of the specific component of distress (Appendix 17).

The order of distribution of the five questionnaires to be completed was randomly varied to eliminate the possibility of an “order” effect (Appendix 18).

4.3. Physical Measures

The participants were informed of the six physical measures requiring examination prior to their assessment. The physical measures were recorded with the participant standing barefoot, to avoid the effect of different shoe types on the collected data.

The six measures (Appendix 19) included:

1. *Height (cm)* recorded by a wall fixed tape measure. The participants were instructed to stand straight, heels against the wall and keep their arms resting by their side. They were then instructed to look straight ahead and focus on the clearly marked coloured cross (X) on the wall in front of them at a distance of 2.5 meters and at a height of 1.5 meters.

2. *Weight (kg)* recorded by the computerized force plate (CFP) (Kistler Type 9286AA; Kistler Group, Switzerland), using the Body Weight Measurement Tool. This tool is a scale that reads real time vertical forces from the CFP. The selected measurement unit of force was kilograms force (kgf).
The participants were instructed to stand in a “comfortable stance” position over the centre of the CFP and keep their arms resting by their sides. As before, they were instructed to look straight ahead and focus on the clearly marked coloured cross (X) on the wall in front. Finally, the participants were instructed to empty their pockets of their “gym gear” prior to the recording of their body weight.

Prior to the commencement of testing, the CFP was calibrated for the weights of 10, 20 and 30 kg against a set of calibrated Masscal Free Weights (Precision Calibration Services P/L, Sydney, Australia – NATA Accredited Laboratory No 1710). The Masscal Free Weights calibration report is attached (Appendix 20). A set of three calibration readings for each selected weight was performed. The force plate was found to have a consistent reading error of 0.04 kg for the whole range. Although the known error was considered to be clinically insignificant, the adjustment of 0.04 kg was still made for each participant’s weight reading prior to its recording and being used for statistical analysis. A table recording the calibration reading results for the three weight settings (Appendix 21) and the Kistler Force Plate Type 9286AA; Serial Number 1092385 calibration certificate (Appendix 22) are attached.

3. *Body Mass Index (BMI) (kg/m²)* is a ratio calculated by dividing the weight (measured in kilograms) by the height squared (measured in meters). This ratio was calculated immediately following the collection of height and weight measures.
4. *Foot Size (Length) (US)* was recorded with a Brannock Professional Foot-Measuring Device (Model – Combination Mens/Womens (US)). The participant was instructed to stand with their feet in a close parallel position and their arms resting by their sides. Again, the participants were instructed to look straight ahead and focus on the clearly marked coloured cross (X) on the wall in front. Slight downward vertical pressure was applied to the nail bed of the first digit to confirm an accurate length reading was recorded.

5. *Foot Width (US)* was also recorded with a Brannock Professional Foot-Measuring Device (Model – Combination Mens/Womens (US)). The measurement was performed with the identical participant position as described for the foot size (Length) (US) measurement. The participants’ results were provided in the standard US scale of A – 3E. A conversion to a matching numerical scale of 1 – 7 was performed to allow this measurement to be statistically analysed as scale data.

Following each participant testing the Brannock Professional Foot-Measuring Device was cleaned with alcohol antibacterial wipes (Mediflex Industries, Sydney, NSW), before testing the next participant.

6. *Leg Dominance* was determined by asking the participant the question “which foot would you most likely use to kick a ball?” (McPartland, Brodeur, & Hallgren, 1997; Riemann & Guskiewicz, 2000). This question was asked immediately prior to sensory threshold testing.
A list summarizing the equipment required to complete the study is contained in the table of appendices (Appendix 23).

4.4. Mechanical Pain Threshold Tests (MPTT)

Pressure Algometric (kg) data represents the mechanical pain detection threshold (MPTT) which is but one quantitative measure of sensitivity to pain. Decreased mechanical pain detection and tolerance thresholds indicate central nervous system (CNS) sensory mechanical hyperalgesia (that is, hypersensitivity to pain).

For the study, recording of pressure pain thresholds were performed at the following two chosen sites:

1. The most symptomatic cervical spine site was indicated by the chronic neck pain participant and confirmed by their previously completed body chart. For the control participants, the articular pillar of C5 / C6 on their non-dominant side was chosen. The latter site was located by counting down from the C2 to the C5 spinous process and then palpating laterally to locate the transverse process of the C5 vertebrae. The articular pillar of C5 / C6 lays just immediately inferior and medial to the transverse process of the C5 vertebrae.

2. An asymptomatic remote site, the tibialis anterior muscle belly, ipsilateral to the chosen cervical spine site.

A hand-held dial Pressure Algometer Device (Baseline Push Pull Force Gauge Model 12 – 0304 (Fabrication Enterprises Inc., New York, USA)), with a circular head size
of 1 cm in diameter, was employed for the study to measure mechanical sensory threshold. Bisset and Evans (2011), using a similar hand-held dial Pressure Algometer Device, demonstrated good inter-tester reliability for pressure pain algometry, even when performed by inexperienced testers. Studies have indicated that higher pressure pain thresholds are recorded at higher pressure application rates (Sterling, 2011). The hand-held dial Pressure Algometer Device (Baseline Push Pull Force Gauge Model 12 – 0304) employed in the study is unable to provide a standardised pressure application rate and this equipment limitation was accepted in the study design.

Prior to the commencement of testing, the Pressure Algometer Device was calibrated for the range of 0 to 10 kg against a Kistler Quattro Jump Force Plate Model 9290AD (Kistler Group, Winterhur, Switzerland). A set of three calibration readings for each selected pressure setting was performed. The pressure algometer was found to have a consistent reading error of 0.30 kg for the whole range. The known error adjustment of 0.30 kg was made for the three readings for each location prior to calculating the mean score used for statistical analysis. A table recording the calibration reading results for each setting is attached (Appendix 24).

The mechanical (pressure) pain threshold was assessed with the participant instructed to stand in a “comfortable stance” position, whilst barefoot and by asking the question “to immediately indicate when the sensation under the pressure algometer changes from pressure alone to pressure and pain”. The application rate was three times for each location and the mean score calculated and used for statistical analysis (Appendix 19). A time interval of at least 30 seconds between each pressure pain threshold test procedure was applied. If a participant indicated pain or a “bruised feeling” following a pressure algometer test, the subsequent tests were performed at
an immediately adjacent site, so as not to unduly affect the subsequent pressure algometer test results.

Following participant testing, the Pressure Algometer Device was cleaned with alcohol antibacterial wipes (Mediflex Industries, Sydney, NSW), before testing the next participant.

4.5. Balance Tests

A brief description of the test equipment was provided to the participants. In addition, the researcher provided an explanation and demonstration of these five balance tests to the participants prior to their actual testing. If required, the participants were allowed a “trial” of any, or all, of the five balance tests. If undertaken, the “trial” for the static balance tests was limited to ten seconds only and the participants were given a five-minute rest period prior to the actual testing to accommodate for potential learning effects.

The time-of-day has been shown to have a consistent influence on postural control, especially when involving dynamic tasks. Gribble, Tucker, and White (2007), for example, have demonstrated that the performance on a postural control task was better in the morning than in the evening and, ultimately, worst in the afternoon. These researchers recommended avoiding the afternoon when conducting an initial assessment of postural control in order to eliminate any detrimental time-of-day influence on the measure. Consequently, where possible the participants for the study were tested in the morning or evening.
The researcher remained with the participants throughout the performance of the five balance tests providing continual observation and verbal assistance, but at no time had manual contact with the participants.

The participants were required to successfully perform the five balance tests to detect alterations in postural sway with a rest period, if required, of up to thirty seconds between each of the balance tests being provided. The participants were instructed to “stand as still as possible” for at least two seconds prior to each balance test, providing a test reference point for each test, thus assisting with data analysis.

Each participant was allowed up to five attempts to successfully complete each of the five balance tests. The result from the first successfully completed balance test for each of the five balance tests was used for data analysis. If the participant was unsuccessful in completing the specific balance test in five attempts, a “failure to complete” was recorded.

Postural sway was simultaneously measured by a laboratory-grade computerized force plate (CFP) (Kistler Type 9286AA; Serial Number 1092385; Kistler Group, Switzerland) and a Smart Phone analog - iPod Touch (Apple Inc., Cupertino, USA) downloaded with the Accelerometer Data Pro Application 2009-2010 (Wavefront Labs., USA), forming the wearable accelerometer, during the five balance tests for the study - refer to Figure 2.2.
The researcher concurrently started the CFP and the SP, following the countdown of “3 – 2 – 1 – start”, to commence the balance tests section of the research project. Simultaneously, the participant started a stopwatch following this countdown to also time the commencement of the balance testing.

The time of the commencement of each balance test was recorded from the stopwatch, which was later correlated against the timed CFP recorded data to guarantee that the correct data segment was chosen for analysis.
The order of the balance tests performance was also randomly allocated to eliminate the possibility of an “order” effect (Appendix 25).

These balance tests (three static and two dynamic tests) were all performed with the participant barefoot, to avoid any effect of different shoe types on the balance data.

Typically, test participants are asked to stand “quietly” during computerized posturography studies (Duarte & Zatsiorsky, 1999), but this is not a functional representation of the majority of everyday activities. The study aimed to replicate “unconstrained” standing and walking, which is more representative of normal daily activities.

The participants were instructed to keep their eyes open at all times whilst looking straight ahead and focusing on the clearly coloured marked cross (X) on the wall in front, at a distance of 2.5 meters. Their arms were required to be resting “naturally” by their sides for the static balance tests, and allowed to “move freely” during the dynamic balance tests.

The balance tests selected for the study included:

1. **Static Balance Test Measures**:

   1. *Single Legged Stance (SLS)* required the participants to step onto the centre of the force plate with their previously determined dominant leg and maintain this position for duration of 30 seconds. Each participant was instructed to hold their non-dominant leg in a position of approximately 30 degrees of hip
flexion and 45 degrees of knee flexion. If the non-stance leg touched the ground before completing the 30 seconds time period, the test was ruled invalid. If required, the participants were allowed to repeat this test for a maximum of five times, with the first successful test result data being recorded. If all the five test attempts were unsuccessful, no test data but a failure to complete was recorded for that participant.

2. *Comfortable Stance (CS)* required the participants to first step onto the centre of the force plate with their previously determined dominant leg which was then followed by placing their non-dominant leg in a self-determined position of comfort on the CFP. Resultant foot placement was approximately shoulder-width apart. The participants were instructed “to evenly distribute their weight over both feet”. This position was maintained for the duration of 30 seconds.

3. *Narrow Stance (NS)* required the participants to first step onto the centre of the force plate with their previously determined dominant leg which was then followed by placing their non-dominant leg parallel and as close as possible to the dominant leg. The participants were advised that their “first toes (1st MTP joint) and ankles (medial malleoli) must be touching” and again “to evenly distribute their weight over both feet”. This position was maintained for the duration of 30 seconds.
All static balance tests were timed with a stopwatch to confirm test duration, with the commencement time being when the participant’s foot first made contact with the CFP (Appendix 26).

Treleaven, Jull, et al. (2005b), showed that only a limited number of neck pain subjects could successfully complete the tandem stance static balance test, and so this test was not considered for the study.

2. Dynamic Balance Test Measures:

1. Normal Walking (NW) required the participant to walk forward “at ease” and at their normal pace, commencing with their dominant leg for a distance of five meters over a previously taped (5 cm thick) straight line. The leg to first strike the force plate and then the second leg, if applicable, were recorded (Appendix 26).

2. Tandem Walking (TW) is also referred to as the ‘Field Sobriety” test. This test requires the participant to walk forward in a “heel-to-toe” method commencing with their dominant leg for a distance of five meters over a previously taped (5 cm thick) straight line. The sequence of the foot strikes across the force plate was recorded.

As increased postural sway measures are known to occur, especially in the ML direction, when dynamic balance tests are commenced with the non-dominant leg (Rigoberto, et al., 2010), the commencement of all balance tests with the dominant leg was used as the standard for the study.
The participants were guided back to the start of the marked five-metre line following completion of each of the dynamic balance test.

For both dynamic balance tests the CFP was positioned at the centre of the measured and marked five-metre line, consequently being at the commencement of the third metre. The researcher recorded each participant’s foot contact (whole or partial) with the CFP.

Postural sway was measured on a stable piezo-electric CFP measuring 600mm X 400mm X 40mm. Centre of pressure force changes, recorded in Newtons (N), in the vertical, anterior-posterior (AP) and medial-lateral (ML) directions were measured, over time, by ground reaction forces registering on the four piezo-electric sensors mounted within the CFP. These three-component force sensors consist of two shear-sensitive quartz washers (Fx and Fy) and one pressure-sensitive quartz washer (Fz). The force changes are converted to electrical signals, filtered and then finally recorded, both numerically (Text File (*.txt)) and graphically (Bioware File (*.dat)). These recorded results were obtained by using the Kistler Bioware Software Version 5.1.1.0x Type 2812A – 04 - 0, 2009 - 2011 computer program. A study by Lin, et al. (2008) has demonstrated the within-day reliability for COP- based postural sway measures, regardless of age. Accordingly, this method of assessment of postural sway is universally accepted as the “gold-standard” reference.

The recorded Text File (numerical data) was then imported into a Spreadsheet File, using Microsoft Excel Worksheet 2010 and saved in the CSV (comma separated values/ comma delimited) format, to facilitate analysis of the numerical data. The resultant three files for all participants were then coded.
To obtain the necessary data from the CFP during balance testing specific settings for the Acquired Data and Export Device Data dialog boxes were required. The CFP Acquired Data dialog box (Model DAQ System for Bioware: Type 5691A; Serial Number 1841184) settings included:

1. **Acquisition Information:**
   
   1. *Direction Control:* On
   
   2. *Trigger:* On a Key
   
   3. *Autosave:* On
   
   4. *Filename (*.dat):* Participant 000.dat
   
   5. *Pretrigger:* Off

2. **Active Devices:**
   
   1. *Name:* Force Plate 2
   
   2. *Type:* Kistler Model Type 9286 AA
   
   3. *Serial Number:* 1092385
   
   4. *Channels:* 9 to 16

3. **Sampling Information:**
1. *Length*: 360 sec. The sampling length was determined following three timed trials of the five balance tests by the researcher and Technical Assistant, Faculty of Health, University of Canberra. Therefore, 36,000 samples for each of the five-balance tests were collected.

2. *Rate*: 100Hz. The sampling rate was selected to match the maximum available sampling rate (frequency) on the Accelerometer Data Pro Application 2009-2010 (Wavefront Labs., USA) forming the wearable accelerometer on the mobile computing platform.

4. *Direction Control*: Forward

5. *Weight*: Units – Newtons (N)

The CFP Export Device Data dialog box settings included:

1. *Device*: Force Plate 2: Kistler Model Type 9286 AA

2. *X Axis*: Absolute Time

3. *Export Parameters*: The selected Performance Parameters included:

   1. *Force*: Fx – Medio-lateral (ML) force

   2. *Force*: Fy – Anterior-posterior (AP) force

   3. *Force*: Fz – Vertical force
As mentioned earlier, the postural sway for each of the five balance tests was simultaneously measured by an accelerometer within a SP (becoming a wearable accelerometer). Atallah, et al. (2010), investigated the optimal wearable accelerometer positioning for different groups of daily activities, since their positioning plays an important role in the pervasiveness and wear ability of these devices. Their study found that for “low-level activities the waist positioning of the accelerometer provided maximal precision and recall. Whilst for medium-level activities the chest and wrist positions provide the best precision rates”.

Since the study was primarily investigating low-level activities, the SP was positioned, with the long axis horizontally, over the antero-lateral aspect of the waist, at a level parallel to the spinous process of the L4 vertebrae, on the side of the participant’s dominant leg. The position was selected as it close to the known centre of mass for the human body (Rigoberto, et al., 2010) and closely represents the location that most people on a daily basis usually store their SP. A similar position has also been found not to restrict the movement of the hips and pelvis in relation to the trunk whilst measuring trunk sway (Sjöström, et al., 2003).

The SP was located inside a Lycra sleeve attached to a purposely designed elastic belt made by SPIbelt (Overton Enterprises., Austin, USA) and fixed to the abovementioned position by an adjustable plastic clip and buckle. The belt was applied in a “firm but comfortable” manner to the participants to reduce the likelihood of any movement whilst testing. This in turn would reduce random sway signals and thus inaccurate data recording. Each participant was asked to “march on the spot”,
performed five times, to ensure both the firmness and position of the SP were not restricting the participant’s normal gait.

For the study, the Accelerometer Data Pro Application 2009-2010 (Wavefront Labs., USA) settings included:

1. **Accelerometer Streaming Data:**
   
   1. **Mode:** Sensor
   
   2. **Enable Streaming:** Off
   
   3. **Values:** X; Y; Z

2. **Accelerometer Capturing Data:**

   1. **URL:** [http://XXX.XXX.X.X.:54388](http://XXX.XXX.X.X.:54388)

   2. **Collection Control:** Freq: 100 Hz. The maximum sampling rate available for data collection and is identical to the sampling rate of the CFP.

   3. **Capture Run Control:** Sampling: On

   4. **Filename:** accel_MMDD_HHMSS.csv. The format for the filename, where MM=Month; DD=Day; HH=Hours (1-24 Hours); MM=Minutes and SS=Seconds.

   5. **Samples:** 0 – 36,000
3. **Configuration setting:**

   1. ***Streaming Data Mode***: Broadcast (by default)

   2. ***Streaming Data Target***:

      1. **Address**: 255.255.255.255

      2. **Port**: 10552

   3. ***Acceleration Data Filtering***: None. Without filtering, only the “raw” data was collected and represented the total acceleration of the SP in three axes. The total acceleration was equal to gravity plus the acceleration the participants imparted to the SP, and was measured in units of g.

4. **Library**:

   The Library allowed the collected data to be viewed and managed by creating a stored data file (Format - accel_MMDD_HHmmss.csv). The file is downloaded as CSV (comma separated) data values by an external web browser to a computer of choice. The downloaded file was then imported into a Spreadsheet File, using Microsoft Excel Worksheet 2010, and saved in the CSV (comma separated values/ comma delimited) format, to facilitate data analysis and finally coded for each participant.

The accelerometer in the iPod Touch measures the acceleration of the SP in three different axes: X, Y, and Z. The reading of these three axes vary depending upon the
position and orientation of the mobile computing platform. For the study, the long axis of the SP was horizontal, in an orientation often referred to as the “left landscape” mode. Accordingly, the Y, Z and X-axes data reading values represented the ML, AP and vertical directions respectively. At rest, Y and Z-axes values are near zero, whilst the X-axis value is near 1.0, due to the force of gravity.

To ensure the position of the accelerometer was kept constant between participants, the screen of the SP was placed towards the participant’s body with the manufacturer’s symbol, located on the opposite side, with the “bite of the apple” being superiorly orientated.

5. Procedure

Participants were tested during a single visit to the Faculty of Health, University of Canberra. On average, the testing was completed within a forty-five minute period. The procedure for each section of the test (4.1 – 4.5) was as outlined above and remained the same for all participants. If required, the participants were allowed a rest period, up to five minutes, having once completed a section of the test.

At the conclusion of testing, to ensure each participant finalized all the required test tasks, a Test Procedure Form (Appendix 27) was completed and checked prior to discharging the participant.

6. Data Processing

For the three static balance tests, the middle 10 seconds of the recorded data readings (the 11th - 20th seconds inclusive) from the CFP and SP were used for the data
analysis. For both of these balance measurement tools, the selected sampling rate (frequency) of 100 Hz resulted in 1,000 data readings being analysed. The selected data of the middle 10 seconds avoided any possible random sways occurring at the commencement or the completion of the balance test.

For the two dynamic balance tests, the data readings from the first whole foot contact with the force plate was chosen for data analysis. Initially the force plate vertical axis (Fz) data readings were imported into a Spreadsheet File, using Microsoft Excel Worksheet 2010, and then converted into a line chart representing a vertical ground reaction force graph for both dynamic balance tests. An example of the participants’ graph for each type of dynamic balance test is attached (Appendix 28). From the evaluation of these graphs, the researcher selected the following criteria to further refine the range of data readings chosen for data analysis:

1. **Normal Walking (NW)** – from the first data reading exceeding 200 Newtons (N) to the second peak that occurs during the push-off component of the stance phase of gait. Data readings below 200 Newtons (N) were excluded because of possible random sways associated with heel strike.

2. **Tandem Walking (TW)** – from the first to the last data reading to equal or exceed the participant’s bodyweight.

The duration for the final selected range of data readings for each of the dynamic balance tests was calculated and recorded (sec). The simultaneously timed data readings from the SP were identified and then recorded for the comparison dynamic balance tests data analysis.
The CFP data readings for the vertical direction (Fz) were then normalized relative to the participant’s anthropometric properties, by dividing each of the recorded data readings value (N units) by the participants’ bodyweight. This conversion was performed for each of the five balance tests and allowed for a true comparison with the simultaneously recorded SP’s data readings. These normalized values were added to the previously created and coded force plate spreadsheet File, using Microsoft Excel Worksheet 2010 and again saved in the CSV (comma separated values/ comma delimited) format.

The analysis of the postural sway with the CFP and SP was undertaken respectively by assessing the centre of pressure force changes and alterations of acceleration in the ML, AP and vertical directions. Since the study aimed to measure the total degree of variance of postural sway in all directions, using both methods of measurement, all selected data readings were first converted to their absolute values, recorded and then recorded prior to data processing.

The recorded data readings for each direction, for each of the five balance tests and for both the CFP and SP, totalling thirty in number, were separated into individual spreadsheet Files, using Microsoft Excel Worksheet 2010 and again saved in the CSV (comma separated values/ comma delimited) format. Finally, these files were coded for each participant in preparation for frequency-domain spectral analysis including Fast Fourier Transform (FFT) data processing.

For the study, the computer software package SIGVIEW32 Version 2.4.0 1995-2012 (SignalLab., USA; Registration Number SEKEGCCIG) was chosen to provide real-
time offline signal frequency spectral and FFT analyses. For the study the Sigview settings included:

1. *File:*

   1. *Open Signal*

   2. *ASC11 Files*

   3. *Import Signal (decimal comma)*

   4. *Look In: Participant Data Reading Folder*

   5. *Filename: (*.dat): Participant 000.dat*

   6. *Files of Type: All Files (*.*)*

   7. *Sample Rate: 100 samples / sec*

   8. *Sample Distance: 0.01 sec*

   9. *Units: sec*

The import signal for the recorded data readings is graphically displayed - blue line chart.

All measurement signals are contaminated with random noise to a greater or lesser degree (Antonsson & Mann, 1985) and the choice of noise removal is arbitrary. As most human movement occurs at a low frequency (Godfrey, Conway, Meagher, &
ÓLaighin, 2008), a cut-off frequency of between 4.0 – 8.0 Hz has been recommended by Bartlett (2007), 0 – 5.0 Hz by Field, et al. (2008), 5.0 – 6.0 Hz by Winter, Sidwall, and Hobson (1974) and 0.6 – 5.0 Hz by Najafi et al. (2003). However, the selected cut-off frequency must include the maximum frequency of interest in the movement (Bartlett, 2007) and the frequency range of 1-3 Hz of postural sway known to be most dependent on proprioceptive inputs (Wada, et al., 2001). In addition, a previously mentioned study has found that 99% of signal power in gait is contained below 15 Hz (Antonsson & Mann, 1985). Based on these findings, the researchers decided on the frequency range of 0 – 12 Hz. The filtered import signal is also a graphically displayed - blue line chart.

2. Signal Tools:

1. Filter:

2. Filter Response: Band pass

3. Frequency Range: From 0 to 12.0 Hz

3. Instruments and Markers:

1. Standard Deviation: Numerical Value & Clock Face Displayed

2. RMS: Numerical Value & Clock Face Displayed

4. FFT Spectrum Analysis:

1. Signal Tools: FFT Spectrum Analysis
The FFT signal is graphically displayed - red line chart.

5. Instruments and Markers:

1. Weighted Mean (Mean Frequency): Numerical Value (Hz) & Clock Face Displayed

2. Maximum Position (with marker): Numerical Value (Hz) & Clock Face Displayed

6. File:

1. Save Workplace:

2. Save In: Participant 000.dat Folder

3. Filename: (*.dat): Participant 000.dat

4. Save as Type: Sigview Workplace (*.sws)

The above four stored numerical measures (values) obtained following filtering and frequency-domain measures analysis including Fast Fourier Transform (FFT) processing for the dominant frequencies, and the calculated duration time of each balance test for each participant were recorded (Appendix 29) and later entered into a table format on a spread sheet File, using Microsoft Excel Worksheet 2010 in preparation for import into the selected computer software package for statistical analysis.
All stored numerical measures were finally scanned for “outliers” (extreme or unusual scores), which once identified, were re-calculated to ensure their accuracy.

7. Statistics

All statistical analyses were performed with the SPSS for Windows package (Version 19.0, 2010; IBM SPSS Inc., Chicago, USA) and with the $p$-values below 0.05 considered to be significant.

Initially, the scale data for all participants, the control and chronic neck pain groups was summarized as a mean +/- standard deviation. The descriptive statistic of range was also obtained for the age, duration of symptoms and prescribed medication data.

The scale data between the groups was then compared using independent samples $t$-tests, including Levene’s Test for Equality of Variances and $t$-test for Equality of Means. When Levene’s Test for Equality of Variances was significant ($\text{Sig (p)} < 0.05$), the homogeneity of variance assumption was violated. Accordingly, equal variances for each group’s set of scores could not be assumed, and the modified version of the $t$-test for Equality of Means – the Welch’s $t$-test was employed. The results of the Levene’s Test for Equality of Variances for all the scale measures are presented in Appendix 30.

The Sharpiro-Wilk test of Normality ($p < 0.05$) was not significant for any of the independent samples $t$-tests statistical analyses. This confirms that the assumption of normality for either group of scores had not been violated and hence they were normally distributed.
The Pearson’s Chi – Square \( \chi^2 \) Test of Contingencies was utilized for the nominal data between groups’ analysis of referral basis and origin of symptoms. The Pearson’s Chi – Square \( \chi^2 \) Test of Contingencies has an expected frequencies assumption that no cells have an expected count of less than five. Since this assumption was violated for the nominal data of occupation and leg dominance, the Fisher’s Exact Test (2-sided) was used in the between group analysis. The Phi co-efficient (\( \phi \)) was employed to determine the measure of association for the statistically significant Pearson’s Chi – Square \( \chi^2 \) Tests of Contingencies.

The bivariate Pearson’s \( r \) correlation coefficient is a measure of association, but it is not appropriate for assessing agreement between two clinical results, as it not sensitive to systematic bias between these results. The Intra-Class Correlation coefficient (ICC) is considered a more robust test for correlation as it is sensitive to systematic bias and can provide a measure of absolute agreement, and therefore interchangeability, between the results (Cathcart & Pritchard, 2006). Since ICC does produce a weaker correlation and thereby increases the probability of not detecting a clinically significant correlation, the bivariate Pearson’s \( r \) correlation coefficient was considered most suitable for the study.

The bivariate Pearson’s \( r \) correlation coefficient was used to determine the linear association, both strength and direction, between each of the following two measures:

1. CFP and SP balance tests AP direction measures - including Raw Standard Deviation (RSD), Root Mean Square (RMS), FFT Mean frequency and FFT Maximum frequency
2. CFP and SP balance tests ML direction measures – including RSD, RMS, FFT Mean frequency and FFT Maximum frequency

3. CFP and SP balance tests vertical direction measures - including RSD, RMS, FFT Mean frequency and FFT Maximum frequency

All the above bivariate Pearson’s r correlation coefficient calculations were initially performed for all participants (n) = 50 and then separately, for both the control and chronic neck pain groups (n) = 25, for each of the static and dynamic balance tests.

4. CFP balance tests - FFT Mean frequency and self-rated questionnaire measures for both the control and chronic neck pain groups (n) = 25

5. SP balance tests - FFT Mean frequency and self-rated questionnaire measures for both the control and chronic neck pain groups (n) = 25

6. CFP balance tests - FFT Mean frequency and mechanical pain threshold tests measures for both the control and chronic neck pain groups (n) = 25

7. SP balance tests - FFT Mean frequency and mechanical pain threshold tests measures for both the control and chronic neck pain groups (n) = 25

8. Self-rated questionnaire and mechanical pain threshold tests measures for the both control and chronic neck pain groups (n) = 25.

Although the four obtained numerical measures from the Filtered and Fast Fourier Transform (FFT) data processing produced values to seven decimal places, for all the
bivariate Pearson’s $r$ correlation coefficient calculations the numerical measures were “rounded” to three decimals places.

Prior to the calculation of all the bivariate Pearson’s $r$ correlation coefficients the assumptions of normality (again, using the Shapiro-Wilk test ($p < 0.05$)) and linearity were tested, and found not to have been violated.

For all participants bivariate Pearson’s $r$ correlation coefficients calculations the number of participants ($n$) = 50 and consequently, the degrees of freedom ($df$) = 48. However, for control or chronic neck pain group bivariate Pearson’s $r$ correlation coefficients calculations the number of participants ($n$) = 25 and consequently, the degrees of freedom ($df$) = 23.
CHAPTER 3

RESULTS

1. Overview

The results of the study are presented in two sections. The first section relates to the descriptive statistics and the independent samples $t$-tests used to compare the mean scores for between test groups difference results. The second section addresses the study’s Pearson’s $r$ correlation coefficients results employed to examine the relationship between the measures of postural sway, self-ratings of pain and disability and mechanical pain threshold testing (MPTT).

2. Between Test-Groups Analyses - Descriptive Statistics and Compared Mean Scores

2.1. Demographic / Historical Data

1. Nominal Measures: Group demographic and history data nominal measures are presented in Appendix 31.

   1. Gender: The Pearson’s Chi-Square $\chi^2$ Test of Contingencies ($p = .05$) showed there was a statistically significant difference between the control and chronic neck pain (CNP) groups, $\chi^2 (1, n = 50) = 12.00, p = .001, \phi$ (phi) = -.49. The measure of association was considered medium
employing Cohen’s criteria (Cohen, 1988). Female participants dominated the CNP group, whereas male participants dominated the control group.

2. **Occupation:** Since the expected frequencies assumption was violated, the Fisher’s Exact Test (2-sided) analysis was used and showed there was a statistically significant difference between the control and chronic neck pain groups, \( p = 0.008, \phi (\text{phi}) = .49 \). The measure of association was considered medium employing Cohen’s criteria (Cohen, 1988). The CNP group was dominated by sedentary workers, whereas the control group was dominated both by students and sedentary workers.

3. **Referral Basis:** The Pearson’s Chi-Square \( \chi^2 \) Test of Contingencies \( (p = .05) \) revealed there was no significant difference between the control and chronic neck pain groups, \( \chi^2 (1, n = 50) = 2.23, p = .136 \).

2. **Scale Measures:** Group demographic and history data scale measures are presented in Appendices 32 and 33.

Independent samples \( t \)-tests were used to compare the mean scores for between groups difference for the demographic and history data scale measures.

1. **Age:** The Levene’s Test for Equality of Variance was significant \( (F = 8.966, p = .004) \) implying equal variances could not be assumed. Accordingly, the Welch’s \( t \)-test was used for the \( t \)-test for Equality of Means analysis and showed no significant difference between the control group \( (M = 44.16, SD = 17.69) \) and the CNP group \( (M = 47.96, SD = 12.82) \), \( t (48) = -.870, p = .389 \), two-tailed.
2. *Number of Prescribed Medications*: The Levene’s Test for Equality of Variance was non-significant implying equal variances could be assumed. The *t*-test for Equality of Means showed no significant difference between the control group (M = 0.48, SD = 1.12) and the CNP group (M = 0.72, SD = 1.21), t (48) = -728, *p* = .407, two-tailed.

### 2.2. Self-Rated Questionnaires (SRQ)

Group self-rated questionnaire measures are presented in Appendix 34.

Independent samples *t*-tests were used to compare the mean scores for between groups difference for all self-rated questionnaire measures. For the following measures the Levene’s Test for Equality of Variance was non-significant, implying equal variances could be assumed:

1. **VAS (Stress)**: The *t*-test for Equality of Means showed no significant difference between the control group (M = 1.63, SD = 2.36) and the CNP group (M = 2.11, SD = 1.82), t (48) = -.800, *p* = .427, two-tailed.
2. **NDI**: The *t*-test for Equality of Means showed a statistically significant difference between the control group (M = 2.84, SD = 3.40) and the CNP group (M = 11.40, SD = 5.35), t (48) = -6.755, *p* < .001, two-tailed.
3. **SF – 36 E/F**: The *t*-test for Equality of Means showed a statistically significant difference between the control group (M = 65.20, SD = 16.68) and the CNP group (M = 54.00, SD = 12.58), t (48) = 2.681, *p* = .01, two-tailed.
4. *SF – 36 SF:* The *t*-test for Equality of Means showed no significant
difference between the control group (M = 89.50, SD = 17.18) and the
CNP group (M = 82.50, SD = 18.75), *t* (48) = 1.376, *p* = .175, two-tailed.

5. *SF – 36 P:* The *t*-test for Equality of Means showed a statistically
significant difference between the control group (M = 86.80, SD = 12.94)
and the CNP group (M = 65.70, SD = 18.84), *t* (48) = 4.616, *p* < .001, two-.tail.

6. *DASS – 21 (D):* The *t*-test for Equality of Means showed no significant
difference between the control group (M = 2.72, SD = 4.31) and the CNP
group (M = 2.56, SD = 2.55), *t* (48) = .160, *p* = .874, two-tailed.

7. *DASS – 21 (A):* The *t*-test for Equality of Means showed no significant
difference between the control group (M = 3.12, SD = 4.04) and the CNP
group (M = 3.44, SD = 3.44), *t* (48) = -.301, *p* = .764, two-tailed.

8. *DASS – 21 (S):* The *t*-test for Equality of Means showed no significant
difference between the control group (M = 8.08, SD = 7.34) and the CNP
group (M = 9.60, SD = 6.53), *t* (48) = -.774, *p* = .443, two-tailed.

However, for the following self-rated questionnaire measures the Levene’s Test for
Equality of Variance was significant, implying equal variances could not be assumed.
Accordingly, the Welch’s *t*-test was used for the *t*-test for Equality of Means analysis:

1. *VAS (Pain):* The Levene’s Test for Equality of Variance was significant (*F* = 5.569, *p* = .022). The Welch’s *t*-test for Equality of Means showed a
statistically significant difference between the control group (M = 0.39,
SD = 0.80) and the CNP group (M = 2.56, SD = 1.33), *t* (48) = -6.990, *p* < .001, two-tailed.
2. **SF – 36 PF:** The Levene’s Test for Equality of Variance was significant (F = 16.585, p < .001). The Welch’s t-test for Equality of Means showed a statistically significant difference between the control group (M = 94.20, SD = 7.46) and the CNP group (M = 79.80, SD = 21.91), t (48) = 3.111, p = .004, two-tailed.

3. **SF – 36 RL - PH:** The Levene’s Test for Equality of Variance was significant (F = 20.400, p < .001). The Welch’s t-test for Equality of Means showed a statistically significant difference between the control group (M = 92.00, SD = 24.71) and the CNP group (M = 63.00, SD = 41.53), t (48) = 3.000, p = .005, two-tailed.

4. **SF – 36 RL – EP:** The Levene’s Test for Equality of Variance was significant (F = 8.601, p = .005). The Welch’s t-test for Equality of Means showed no significant difference between the control group (M = 90.67, SD = 24.57) and the CNP group (M = 78.67, SD = 39.53), t (48) = 1.289, p = .205, two-tailed.

5. **SF – 36 EW - B:** The Levene’s Test for Equality of Variance was significant (F = 4.040, p = .050). The Welch’s t-test for Equality of Means showed no significant difference between the control group (M = 82.56, SD = 14.04) and the CNP group (M = 79.52, SD = 8.43), t (48) = .928, p = .359, two-tailed.

6. **SF – 36 GH:** The Levene’s Test for Equality of Variance was significant (F = 4.713, p = .035). The Welch’s t-test for Equality of Means showed a statistically significant difference between the control group (M = 78.20, SD = 13.14) and the CNP group (M = 64.20, SD = 19.98), t (48) = 2.927, p = .006, two-tailed.
2.3. Physical Measures

1. **Nominal Measure**: The group physical nominal measure is presented in Appendix 35.

   Once more, since the expected frequencies assumption was violated, the Fisher’s Exact Test (2-sided) analysis was used and showed there was non-significant difference between the control and chronic neck pain groups for *Leg Dominance – Left / Right*: $p = 1.000$.

2. **Scale Measures**: Group physical scale measures are presented in Appendix 36. Independent samples t-tests were used to compare the mean scores for between groups difference for all physical scale measures. For the following measures the Levene’s Test for Equality of Variance was non-significant, implying equal variances could be assumed:

   1. **Height**: The t-test for Equality of Means showed no significant difference between the control group (M = 172.89, SD = 8.85) and the CNP group (M = 168.68, SD = 7.89), $t(48) = 1.773, p = .083$, two-tailed.

   2. **Weight**: The t-test for Equality of Means showed no significant difference between the control group (M = 71.22, SD = 13.36) and the CNP group (M = 70.34, SD = 10.70), $t(48) = .259, p = .796$, two-tailed.

   3. **BMI**: The t-test for Equality of Means showed no significant difference between the control group (M = 23.71, SD = 3.50) and the CNP group (M = 24.88, SD = 4.78), $t(48) = -.985, p = .329$, two-tailed.

   4. **Foot Size (US) – Left**: The t-test for Equality of Means showed no significant difference between the control group (M = 8.89, SD = 1.73)

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and the CNP group (M = 8.16, SD = 1.67), t (48) = 1.521, p = .135, two-tailed.

5. Foot Size (US) – Right: The t-test for Equality of Means showed no significant difference between the control group (M = 9.01, SD = 1.64) and the CNP group (M = 8.26, SD = 1.66), t (48) = 1.606, p = .115, two-tailed.

6. Foot Width (US) – Right: The t-test for Equality of Means showed a statistically significant difference between the control group (M = 3.82, SD = 1.16) and the CNP group (M = 3.18, SD = 1.02), t (48) = 2.070, p = .044, two-tailed.

However, for the remaining physical scale measure of Foot Width (US) – Left: the Levene’s Test for Equality of Variance was significant (F = 8.803, p = .005) implying equal variances could not be assumed. Accordingly, the Welch’s t-test was used for the t-test for Equality of Means analysis and showed a statistically significant difference between the control group (M = 3.98, SD = 1.45) and the CNP group (M = 2.94, SD = 0.87), t (48) = 3.069, p = .004, two-tailed.

2.4. Mechanical Pain Threshold Tests (MPTT)

Mechanical pain threshold measures are presented in Appendix 37.

Independent samples t-tests were used to compare the mean scores for between groups difference for both mechanical pain threshold measures. For these measures the Levene’s Test for Equality of Variance was non-significant, implying equal variances could be assumed for the following:
1. **Cervical Spine Site:** The *t*-test for Equality of Means showed a statistically significant difference between the control group (M = 2.87, SD = 0.88) and the CNP group (M = 2.04, SD = 0.90), *t* (48) = 3.322, *p* = .002, two-tailed.

2. **Asymptomatic Remote Site:** The *t*-test for Equality of Means showed a statistically significant difference between the control group (M = 6.77, SD = 1.99) and the CNP group (M = 5.11, SD = 1.93), *t* (48) = 2.985, *p* = .004, two-tailed.

### 2.5. Balance Tests – FFT Mean Frequency Measures

1. Balance tests - FFT Mean frequency measures in the anterior-posterior (AP) direction for the control and chronic neck pain groups are presented in Appendix 38.

   Independent samples *t*-tests were used to compare the mean scores for between groups difference for all balance tests – FFT mean frequency measures in the AP direction. For the following measures the Levene’s Test for Equality of Variance was non-significant, implying equal variances could be assumed:

   1. **CFP SLS Mean Y:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 3.72, SD = 0.64) and the CNP group (M = 3.68, SD = 0.42), *t* (48) = .261, *p* = .796, two-tailed.

   2. **CFP CS Mean Y:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 3.69, SD = 0.59) and the CNP group (M = 3.46, SD = 0.52), *t* (48) = 1.477, *p* = .146, two-tailed.
3. **CFP NS Mean Y**: The t-test for Equality of Means showed no significant difference between the control group (M = 3.43, SD = 0.52) and the CNP group (M = 3.19, SD = 0.47), t (48) = 1.740, p = .088, two-tailed.

4. **CFP NW Mean Y**: The t-test for Equality of Means showed no significant difference between the control group (M = 3.51, SD = 1.33) and the CNP group (M = 2.93, SD = 0.75), t (48) = 1.901, p = .063, two-tailed.

5. **CFP TW Mean Y**: The t-test for Equality of Means showed no significant difference between the control group (M = 3.33, SD = 0.68) and the CNP group (M = 3.35, SD = 0.77), t (48) = -.065, p = .949, two-tailed.

6. **Smart Phone (SP) SLS Mean Z**: The t-test for Equality of Means showed no significant difference between the control group (M = 5.07, SD = 0.75) and the CNP group (M = 4.95, SD = 0.87), t (48) = .538, p = .593, two-tailed.

7. **SP CS Mean Z**: The t-test for Equality of Means showed no significant difference between the control group (M = 4.62, SD = 0.93) and the CNP group (M = 4.33, SD = 0.84), t (48) = 1.18, p = .245, two-tailed.

8. **SP NS Mean Z**: The t-test for Equality of Means showed no significant difference between the control group (M = 4.29, SD = 0.82) and the CNP group (M = 4.05, SD = 0.64), t (48) = .361, p = .262, two-tailed.

9. **SP NW Mean Z**: The t-test for Equality of Means showed no significant difference between the control group (M = 4.14, SD = 1.01) and the CNP group (M = 4.43, SD = 0.91), t (48) = -.083, p = .934, two-tailed.

10. **SP TW Mean Z**: The t-test for Equality of Means showed no significant difference between the control group (M = 4.14, SD = 0.83) and the CNP group (M = 4.01, SD = 0.77), t (48) = .822, p = .570, two-tailed.
However, for the remaining balance tests – FFT mean frequency measure in the AP direction of \textit{FP SLS Mean Y}: the Levene’s Test for Equality of Variance was significant (F = 4.806, \( p = .033 \)) implying equal variances could not be assumed. Accordingly, the Welch’s \( t \)-test was used for the \( t \)-test for Equality of Means analysis and showed no significant difference between the control group (M = 3.72, SD = 0.64) and the CNP group (M = 3.68 SD = 0.42), \( t \) (48) = .261, \( p = .796 \), two-tailed.

2. Balance tests – FFT Mean frequency measures in the medio-lateral (ML) direction for the control and chronic neck pain groups are presented in Appendix 39. Independent samples \( t \)-tests were used to compare the mean scores for between groups difference for all balance tests – FFT mean frequency measures in the \textit{ML direction}. For all measures the Levene’s Test for Equality of Variance was non-significant, implying equal variances could be assumed:

1. \textit{CFP SLS Mean X}: The \( t \)-test for Equality of Means showed no significant difference between the control group (M = 4.07, SD = 0.62) and the CNP group (M = 3.88, SD = 0.53), \( t \) (48) = 1.117, \( p = .270 \), two-tailed.

2. \textit{CFP CS Mean X}: The \( t \)-test for Equality of Means showed no significant difference between the control group (M = 3.71, SD = 0.52) and the CNP group (M = 3.58, SD = 0.70), \( t \) (48) = .767, \( p = .447 \), two-tailed.

3. \textit{CFP NS Mean X}: The \( t \)-test for Equality of Means showed no significant difference between the control group (M = 3.19, SD = 0.46) and the CNP group (M = 3.26, SD = 0.51), \( t \) (48) = -.486, \( p = .629 \), two-tailed.
4. *CFP NW Mean X*: The *t*-test for Equality of Means showed no significant difference between the control group (M = 3.72, SD = 0.98) and the CNP group (M = 4.06, SD = 0.92), *t* (48) = 1.259, *p* = .214, two-tailed.

5. *CFP TW Mean X*: The *t*-test for Equality of Means showed no significant difference between the control group (M = 4.41, SD = 0.77) and the CNP group (M = 4.22, SD = 0.71), *t* (48) = 0.945, *p* = .349, two-tailed.

6. *SP SLS Mean Y*: The *t*-test for Equality of Means showed a statistically significant difference between the control group (M = 5.01, SD = 0.55) and the CNP group (M = 4.65, SD = 0.57), *t* (48) = 2.249, *p* = .029, two-tailed.

7. *SP CS Mean Y*: The *t*-test for Equality of Means showed no significant difference between the control group (M = 4.70, SD = 0.56) and the CNP group (M = 4.40, SD = 0.66), *t* (48) = 1.728, *p* = .090, two-tailed.

8. *SP NS Mean Y*: The *t*-test for Equality of Means showed no significant difference between the control group (M = 4.47, SD = 0.62) and the CNP group (M = 4.36, SD = 0.52), *t* (48) = .693, *p* = .491, two-tailed.

9. *SP NW Mean Y*: The *t*-test for Equality of Means showed no significant difference between the control group (M = 4.55, SD = 0.67) and the CNP group (M = 4.40, SD = 1.06), *t* (48) = .609, *p* = .545, two-tailed.

10. *SP TW Mean Y*: The *t*-test for Equality of Means showed no significant difference between the control group (M = 4.48, SD = 0.68) and the CNP group (M = 4.34, SD = 0.55), *t* (48) = .763, *p* = .449, two-tailed.

3. Balance tests – FFT Mean frequency measures in the vertical direction for the control and chronic neck pain groups are presented in Appendix 40.
Independent samples *t*-tests were used to compare the mean scores for between groups difference for all balance tests – FFT mean frequency measures in the vertical direction. For all measures the Levene’s Test for Equality of Variance was non-significant, implying equal variances could be assumed:

**1. CFP SLS Mean Z:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 4.90, SD = 0.43) and the CNP group (M = 4.89, SD = 0.49), t (48) = 1.101, *p* = .920, two-tailed.

**2. CFP CS Mean Z:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 5.73, SD = 0.46) and the CNP group (M = 5.52, SD = 0.53), t (48) = 1.481, *p* = .145, two-tailed.

**3. CFP NS Mean Z:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 5.42, SD = 0.60) and the CNP group (M = 5.55, SD = 0.51), t (48) = -0.844, *p* = .403, two-tailed.

**4. CFP NW Mean Z:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 2.84, SD = 0.98) and the CNP group (M = 2.85, SD = 0.97), t (48) = -0.029, *p* = .977, two-tailed.

**5. CFP TW Mean Z:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 4.29, SD = 0.52) and the CNP group (M = 4.19, SD = 0.51), t (48) = .694, *p* = .491, two-tailed.

**6. SP SLS Mean X:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 6.49, SD = 0.63) and the CNP group (M = 6.26, SD = 0.48), t (48) = 1.435, *p* = .518, two-tailed.

**7. SP CS Mean X:** The *t*-test for Equality of Means showed no significant difference between the control group (M = 6.20, SD = 0.65) and the CNP group (M = 5.89, SD = 0.50), t (48) = 1.898, *p* = .064, two-tailed.
8. *SP NS Mean X*: The *t*-test for Equality of Means showed a statistically significant difference between the control group (M = 6.09, SD = 0.62) and the CNP group (M = 5.60, SD = 0.56), *t*(48) = 2.925, *p* = .005, two-tailed.

9. *SP NW Mean X*: The *t*-test for Equality of Means showed no significant difference between the control group (M = 5.14, SD = 1.01) and the CNP group (M = 4.95, SD = 0.71), *t*(48) = .774, *p* = .443, two-tailed.

10. *SP TW Mean X*: The *t*-test for Equality of Means showed no significant difference between the control group (M = 5.50, SD = 0.95) and the CNP group (M = 5.24, SD = 0.79), *t*(48) = 1.206, *p* = .310, two-tailed.

3. Correlations

3.1. Computerised Force Plate (CFP) and Smart Phone (SP) – Frequency-Domain Measures

The number of significant Pearson’s *r* correlation coefficients between CFP and SP for the frequency-domain measures in AP, ML & vertical directions for the five balance tests and for all participants, the control and chronic neck pain groups are presented in Appendix 41.

1. “*All Participants*”: For all three directions the FFT Mean frequency was shown to be the most valid measure, with the highest number of significant positive Pearson’s *r* correlation coefficients between the CFP and SP results. The second most correlated measure was Raw Standard Deviation (RSD) for the ML and vertical directions and the FFT maximum frequency
for the AP direction. The RMS measure produced only one significant Pearson’s $r$ correlation coefficient, that for the vertical direction.

2. **Group Allocation:** For the control group again the FFT Mean frequency was shown to be the most valid measure, with the highest number of significant Pearson’s $r$ correlation coefficients between the CFP and SP results, for the AP and ML directions. Equal in highest number of significant Pearson’s $r$ correlation coefficients was the SD measure for the vertical direction. The RMS measure produced no significant Pearson’s $r$ correlation coefficients in any of the three directions.

For the chronic neck pain group the FFT Mean frequency was shown to be the most valid measure, with the highest number of significant Pearson’s $r$ correlation coefficients between the CFP and SP results, for only the AP direction. The SD measure was the most valid measure for the ML direction and demonstrated the equal highest number of significant Pearson’s $r$ correlation coefficients with the FFT maximum frequency measure for the vertical direction. The RMS measure produced only one significant Pearson’s $r$ correlation coefficient, that for the AP direction.

Since, the FFT Mean frequency was shown overall to be the most valid frequency spectral analysis measure of postural sway for all participants and group allocation, this measure was selected for all future bivariate Pearson’s $r$ correlation coefficients statistical analyses between the balance test measures and clinical parameters. Equivalent results were recorded for the ML and AP directions, for all participants and the control and chronic neck pain groups, when totalling the number of
significant Pearson’s $r$ correlation coefficients for all four frequency spectral analysis measures. However, for the vertical direction the control group recorded only half the number of significant Pearson’s $r$ correlation coefficients and the chronic neck pain group a third, compared to all participants.

Likewise, after totalling the number of significant Pearson’s $r$ correlation coefficients for all four frequency spectral analysis measures, the chronic neck pain group recorded the lowest number for all three directions when compared to all participants and the control group. Only for the vertical direction did the results differ between all participants and the control group.

### 3.2. Computerised Force Plate (CFP) and Smart Phone (SP) – FFT Mean Frequency Measures

Correlations between CFP and SP balance tests - FFT Mean frequency measures in AP, ML & vertical directions for each balance test for all participants are presented in Appendix 42.

The bivariate Pearson’s $r$ correlation coefficient was calculated to assess the strength and direction of the linear association between CFP and Smart Phone FFT Mean frequency measures in the AP, ML & vertical directions for the five balance tests. The interpretation of the strength of the linear association was made employing Cohen’s criteria (Cohen, 1988).
1. *AP Direction:*

1. **SLS:** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r (48) = .473$, $p = .001$.

2. **CS:** The bivariate correlation between the two variables was statistically significant, positive and strong, $r (48) = .527$, $p < .001$.

3. **NS:** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r (48) = .458$, $p = .001$.

4. **NW:** The bivariate correlation between the two variables was not statistically significant, $r (48) = .206$, $p = .151$.

5. **TW:** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r (48) = .475$, $p < .001$.

2. *ML Direction:*

1. **SLS:** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r (48) = .392$, $p = .005$.

2. **CS:** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r (48) = .460$, $p = .001$. 


3. **NS:** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r(48) = .437, p = .002$.

4. **NW:** The bivariate correlation between the two variables was not statistically significant, $r(48) = .266, p = .061$.

5. **TW:** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r(48) = .488, p = .001$.

3. **Vertical Direction:**

1. **SLS:** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r(48) = .437, p = .001$.

2. **CS:** The bivariate correlation between the two variables was not statistically significant, $r(48) = .105, p = .469$.

3. **NS:** The bivariate correlation between the two variables was not statistically significant, $r(48) = -.045, p = .756$.

4. **NW:** The bivariate correlation between the two variables was statistically significant, positive and weak, $r(48) = .282, p = .047$.

5. **TW:** The bivariate correlation between the two variables was statistically significant, positive and weak, $r(48) = .297, p = .036$.

Equivalent numbers (four) of significant Pearson’s $r$ correlation coefficients were recorded for the ML and AP directions. However, the AP direction recorded a stronger correlation coefficient for all balance tests except for TW. The vertical
direction recorded three significant Pearson’s $r$ correlation coefficients. The SLS and TW balance tests recorded significant Pearson’s $r$ correlation coefficients in all directions, with the TW balance test recording the stronger correlation coefficient for all but the vertical direction. The NW balance test recorded a significant Pearson’s $r$ correlation coefficient only for the vertical direction.

Correlations between CFP and Smart Phone balance tests - FFT Mean frequency measures in AP, ML & vertical directions for each balance test for the control group are presented in Appendix 43.

Correlations between CFP and Smart Phone balance tests - FFT Mean frequency measures in AP, ML & vertical directions for each balance test for the chronic neck pain group are presented in Appendix 44.

Although the results provided in Appendices 43 and 44 were not individually listed, identical number of significant Pearson’s $r$ correlation coefficients results for all participants were found for the control group when analysing the FFT Mean frequency measures in AP, ML & vertical directions for each balance test. However, for the chronic neck pain group only three significant Pearson’s $r$ correlation coefficients were recorded for the AP direction for the balance tests of SLS, CS and TW. Two significant Pearson’s $r$ correlation coefficients were recorded for the ML direction for the balance tests of CS and NS and none for the vertical direction.
3.3. Computerised Force Plate (CFP) – FFT Mean Frequency and Self-Rating Questionnaires (SRQ) Measures

The number of significant Pearson’s $r$ correlation coefficients between CFP FFT Mean frequency and the self-rating questionnaire measures in AP, ML & vertical directions for both the control and chronic neck pain groups are presented in Appendix 45.

The bivariate Pearson’s $r$ correlation coefficient was calculated to assess the strength and direction of the linear association between CFP FFT Mean frequency and self-rated questionnaire measures in the AP, ML & vertical directions for the five balance tests and for both the control and chronic neck pain groups. The interpretation of the strength of the linear association was made employing Cohen’s criteria (Cohen, 1988).

The statistically significant bivariate Pearson’s $r$ correlation coefficient results included:

1. **AP Direction:**

   1. **Control Group:**

      1. *CFP SLS Mean Y - SF – 36 RL - PH:* The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.471, p = .017.$
2. *CFP TW Mean Y - DASS – 21 (A)*: The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r(23) = -0.409, p = .042 \).

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2. **Chronic Neck Pain Group:**

1. *CFP NW Mean Y – VAS (Pain)*: The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r(23) = 0.412, p = .041 \).

2. *CFP NW Mean Y - DASS – 21 (S)*: The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r(23) = -0.406, p = .044 \).

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2. **ML Direction:**

1. **Control Group:**

1. *CFP SLS Mean X - SF – 36 RL - PH*: The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r(23) = -0.484, p = .014 \).

2. *CFP NS Mean X – VAS (Stress)*: The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r(23) = -0.411, p = .041 \).
2. **Chronic Neck Pain Group:**

1. *CFP NW Mean X - NDI:* The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r (23) = .422, p = .035. \)

2. *CFP NW Mean X - SF – 36 PF:* The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r (23) = .461, p = .020. \)

3. **Vertical Direction:**

   1. **Control Group:**

      1. *CFP SLS Mean Z - SF – 36 RL - EP:* The bivariate correlation between the two variables was statistically significant, negative and strong, \( r (23) = .532, p = .006. \)

      2. *CFP SLS Mean Z - DASS – 21 (D):* The bivariate correlation between the two variables was statistically significant, positive and strong, \( r (23) = .566, p = .003 \)

      3. *CFP SLS Mean Z - DASS – 21 (A):* The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r (23) = .442, p = .027 \)

      4. *CFP NS Mean Z - SF – 36 GH:* The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r (23) = .406, p = .044 \)
5. **CFP NS Mean Z - SF – 36 EW-B**: The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r(23) = -.413, p = .040 \)

6. **CFP TW Mean Z - DASS – 21 (D)**: The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r(23) = -.428, p = .033 \)

2. **Chronic Neck Pain Group**:

   1. **CFP NS Mean Z - DASS – 21 (A)**: The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r(23) = -.437, p = .029 \).

3.4. **Smart Phone (SP) – FFT Mean Frequency and Self-Rating Questionnaires (SRQ) Measures**

The number of significant Pearson’s \( r \) correlation coefficients between SP FFT Mean frequency and self-rating questionnaire measures in AP, ML & vertical directions for both the control and chronic neck pain groups are presented in Appendix 46.

The bivariate Pearson’s \( r \) correlation coefficient was calculated to assess the strength and direction of the linear association between wearable SP FFT Mean frequency and the fourteen self-rated questionnaire measures in the AP, ML & vertical directions for the five balance tests and for both the control and chronic neck pain groups. The interpretation of the strength of the linear association was made employing Cohen’s criteria (Cohen, 1988).
The statistically significant bivariate Pearson’s $r$ correlation coefficient results included:

1. **AP Direction:**

   1. **Control Group:**

      1. *SP SLS Mean Y - SF – 36 RL - EP:* The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.433, p = .031$.
      2. *SP SLS Mean Y - SF – 36 P:* The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.432, p = .031$.
      3. *SP SLS Mean Y - DASS – 21 (A):* The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.462, p = .020$.
      4. *SP NS Mean Y - DASS – 21 (D):* The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.408, p = .043$.
      5. *SP TW Mean Y - SF – 36 PF:* The bivariate correlation between the two variables was statistically significant, positive and strong, $r (23) = .509, p = .009$.
      6. *SP TW Mean Y - DASS – 21 (A):* The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.474, p = .017$. 

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2. *Chronic Neck Pain Group:*

1. *SP SLS Mean Y – VAS (Pain):* The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r (23) = -.477, p = .016. \)

2. *SP SLS Mean Y - SF – 36 E – F:* The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r (23) = .481, p = .015. \)

3. *SP CS Mean Y – SF – 36 SF:* The bivariate correlation between the two variables was statistically significant, negative and strong, \( r (23) = -.520, p = .008. \)

4. *SP CS Mean Y - DASS – 21 (D):* The bivariate correlation between the two variables was statistically significant, positive and strong, \( r (23) = .577, p = .003. \)

5. *SP NW Mean Y – SF – 36 E – F:* The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r (23) = -.446, p = .025. \)

2. *ML Direction:*

1. *Control Group:*

   1. *SP CS Mean X - VAS (Pain):* The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r (23) = .444, p = .026. \)
2. *SP TW Mean X – VAS (Pain)*: The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r (23) = .493, p = .012 \).

3. **Vertical Direction:**

   1. **Control Group:**

      1. *SP TW Mean Z - SF – 36 PF*: The bivariate correlation between the two variables was statistically significant, negative and strong, \( r (23) = -.512, p = .009 \).
      2. *SP TW Mean Z – SF – 36 E – F*: The bivariate correlation between the two variables was statistically significant, positive and strong, \( r (23) = .495, p = .012 \)
      3. *SP TW Mean Z – DASS – 21 (A)*: The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r (23) = -.405, p = .044 \)

   2. **Chronic Neck Pain Group:**

      1. *SP SLS Mean Z – VAS (Pain)*: The bivariate correlation between the two variables was statistically significant, negative and moderate, \( r (23) = -.408, p = .043 \).
      2. *SP SLS Mean Z – SF – 36 P*: The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r (23) = .397, p = .049 \).
3.5. Computerised Force Plate (CFP) – FFT Mean Frequency and Mechanical Pain Threshold Testing (MPTT) Measures

The number of significant Pearson’s $r$ correlation coefficients between CFP FFT Mean frequency and mechanical pain threshold testing measures in AP, ML & vertical directions for both the control and chronic neck pain groups are presented in Appendix 47.

The bivariate Pearson’s $r$ correlation coefficient was calculated to assess the strength and direction of the linear association between CFP FFT mean frequency and mechanical pain threshold measures in the AP, ML & vertical directions for the five balance tests and for both the control and chronic neck pain groups. The interpretation of the strength of the linear association was made employing Cohen’s criteria (Cohen, 1988).

The only statistically significant bivariate Pearson’s $r$ correlation coefficient result was:

1. **Vertical Direction:**

   1. *Chronic Neck Pain Group:*

      1. **CFP TW Mean Z – Cervical Spine Site (Most Painful):** The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.464, p = .020$. 
3.6. Smart Phone (SP) – FFT Mean Frequency and Mechanical Pain Threshold Tests (MPTT) Measures

The number of significant Pearson’s $r$ correlation coefficients between SP FFT Mean frequency and mechanical pain threshold measures in AP, ML & vertical directions for both the control and chronic neck pain groups are presented in Appendix 48.

The bivariate Pearson’s $r$ correlation coefficient was calculated to assess the strength and direction of the linear association between Smart Phone FFT Mean frequency and mechanical pain threshold measures in the AP, ML & vertical directions for the five balance tests and for both the control and chronic neck pain groups. The interpretation of the strength of the linear association was made employing Cohen’s criteria (Cohen, 1988).

The statistically significant bivariate Pearson’s $r$ correlation coefficient results included:

1. **AP Direction:**

   1. **Control Group:**

      1. *SP SLS Mean Y – Asymptomatic Remote Site (TA muscle Belly):* The bivariate correlation between the two variables was statistically significant, positive and strong, $r (23) = .496, p = .012.$
2. Chronic Neck Pain Group:

1.  *SP SLS Mean Y – Cervical Spine Site (Most Painful):*  
The bivariate correlation between the two variables was statistically significant, positive and strong, \( r (23) = - .516, p = .008 \).

2.  *ML Direction:*

1.  *Control Group:*

   1.  *SP CS Mean X - Asymptomatic Remote Site (TA muscle Belly):*  
The bivariate correlation between the two variables was statistically significant, positive and moderate, \( r (23) = .475, p = .017 \).

3.  *Vertical Direction:*

   1.  *Chronic Neck Pain Group:*

      1.  *SP SLS Mean Z – Cervical Spine Site (Most Painful):*  
The bivariate correlation between the two variables was statistically significant, positive and strong, \( r (23) = - .571, p = .003 \).
3.7. Self-Rated Questionnaires (SRQ) and Mechanical Pain Threshold Testing (MPTT) Measures

1. Control Group: Correlations between self-rated questionnaire and mechanical pain threshold testing measures for the control group are presented in Appendix 49.

The bivariate Pearson’s $r$ correlation coefficient was calculated to assess the strength and direction of the linear association between self-rated questionnaire and mechanical pain threshold measures for the control group. The interpretation of the strength of the linear association was made employing Cohen’s criteria (Cohen, 1988).

The statistically significant bivariate Pearson’s $r$ correlation coefficient results included:

1. VAS (Stress) - MPTT Cervical Spine Site (C5 / C6 AP): The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.401, p = .047$.

2. NDI - MPTT Cervical Spine Site (C5 / C6 AP): The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.491, p = .013$.

3. SF – 36 SF - MPTT Cervical Spine Site (C5 / C6 AP): The bivariate correlation between the two variables was statistically significant, positive and moderate, $r (23) = .398, p = .049$.

4. DASS – 21 (A) - MPTT Cervical Spine Site (C5 / C6 AP): The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.435, p = .030$. 

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2. Chronic Neck Pain Group: Correlations between self-rated questionnaire and mechanical pain threshold measures for the chronic neck pain group are presented in Appendix 50.

The bivariate Pearson’s $r$ correlation coefficient was calculated to assess the strength and direction of the linear association between self-rated questionnaire and mechanical pain threshold measures for the chronic neck pain group. The interpretation of the strength of the linear association was made employing Cohen’s criteria (Cohen, 1988).

The statistically significant bivariate Pearson’s $r$ correlation coefficient results included:

1. **VAS (Pain) - MPTT Cervical Spine Site (Most Painful):** The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.402, p = .047$.

2. **NDI - MPTT Cervical Spine Site (Most Painful):** The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.478, p = .013$.

3. **NDI - MPTT Asymptomatic Remote Site (TA Muscle Belly):** The bivariate correlation between the two variables was statistically significant, negative and moderate, $r (23) = -.499, p = .011$.

4. **SF – 36 PF - MPTT Cervical Spine Site (Most Painful):** The bivariate correlation between the two variables was statistically significant, positive and moderate, $r (23) = .484, p = .014$. 
5. *SF – 36 GH - MPTT Cervical Spine Site (Most Painful):* The bivariate correlation between the two variables was statistically significant, positive and strong, $r (23) = .534, p = .006$.

6. *SF – 36 GH - MPTT Asymptomatic Remote Site (TA Muscle Belly):* The bivariate correlation between the two variables was statistically significant, positive and moderate, $r (23) = .458, p = .021$. 
CHAPTER 4

DISCUSSION

1. Overview

The Smart Phone (SP) measures of postural sway in the normal sample population in the study assessed are valid when compared to those of the computerised force plate (CFP). In the chronic neck pain (CNP) sufferers the SP measures are valid in the anterior-posterior (AP) direction during the more challenging single leg stance (SLS) and tandem walking (TW) balance tests. The most valid frequency-domain measure for assessing postural sway was the Fast Fourier Transform (FFT) Mean Frequency. The SP demonstrates a greater capacity than the CFP in detecting the relationship between postural sway and self-rating of pain and disability measures. Lastly, the relationship between the various self-rating of pain and disability and mechanical pain threshold testing (MPTT) measures are only demonstrated for the physical health summary component in CNP sufferers.

The SP with appropriate software, used as a wearable accelerometer has the potential to become an inexpensive and easily accessible tool for quantitatively measuring postural sway suitable for the clinical practice environment. Subsequently, a valuable clinical assessment and feedback device for balance is created. Possible benefits are earlier detection and better on-going monitoring of postural sway changes and the immediate assessment of treatment interventions leading to improved rehabilitation outcomes and potentially reduce falls-related injuries in CNP sufferers from balance...
disturbances. These benefits could also apply to sufferers experiencing balance disturbances arising from other orthopaedic, sports, neurological, geriatric or paediatric conditions.

The following discussion presents a detailed assessment of the validity of the SP measures of postural sway during both static and dynamic balance tests compared to those of the known “gold-standard” reference of a laboratory-grade CFP in all participants, and those with and without CNP. An examination of the relationships between the measures of postural sway, self-ratings of pain and disability and MPTT in participants with and without CNP are presented. The highlights, and their implications, of the between test-groups compared mean scores for the demographic / historical, physical, self-rating questionnaires (SRQ) and MPTT measures are also addressed. Finally, a review of the study’s contribution(s) to research, limitations, clinical practice implications, future research directions and conclusions are outlined.

2. Validating the Use of Smart Phones (SP) for Balance Assessment

2.1 Computerised Force Plate and Smart Phone – Frequency-Domain Spectral Measures

The three static balance tests of SLS, comfortable stance (CS) and narrow stance (NS) and two dynamic balance tests of normal walking (NW) and TW were used to test the validity of the SP measures of postural sway when compared to those of the known “gold-standard” reference of a laboratory-grade CFP. The strength of the validity was tested for three populations: all participants (combined control and CNP groups) and those of the control and CNP groups.
The Pearson’s $r$ correlation coefficients for “all participants” (combined control and CNP groups) achieved the primary aim of the study that quantitative measures of postural sway during both static and dynamic balance tests, obtained from the SP are valid when compared to those from the laboratory-grade CFP.

The FFT Mean frequency measure, producing the highest number of statistically significant Pearson’s $r$ correlation coefficients between the laboratory-grade CFP and SP results, is the most valid frequency spectral measure of postural sway in the anterior-posterior (AP), medio-lateral (ML) and vertical directions. The CFP frequency-domain measure result is consistent with the results of previous studies by McClenaghan, et al. (1996) and Cherng, et al. (2003), thereby confirming the validity of the SP measures. The two major limitations of other wearable balance devices proposed by other researchers, including Clark, et al. (2010); Haas and Burden (2000) and Wang, et al. (2010), relate to their ability to only assess static balance in two axial directions. These limitations are overcome by the SP, shown to be capable of determining postural sway in all three axial directions, during both static and dynamic balance testing.

The FFT Mean frequency measure results analysis in the AP and ML directions produced significant correlation coefficients for the SLS, CS, NS and TW balance tests. For all these balance tests, except the TW, the AP direction, demonstrating a stronger correlation, was the better match. The result supports the systematic literature review by Ruhe, et al. (2011) and findings by Cherng, et al. (2003), Vuillerme and Pinsault (2009), Goto, et al. (2011), Wada, et al. (2001), Field, et al. (2008) and Madeleine, et al. (2004) demonstrating that the AP direction was the most significant direction in detecting increases of postural sway in healthy individuals and CNP
sufferers. The significant correlation between the SP and CFP FFT Mean frequency results for both the AP and ML directions indicate that any movement of the SP inside the SPIbelt did not appear to substantially influence the postural sway measures results for the study.

The result that the AP direction produced stronger correlation coefficients than the ML direction, may relate to the physical measure of foot width. The explanation is supported by Alonso, et al. (2012) Chiari, et al. (2002), and Chou, et al. (2009) who found an increase in total stance width, directly related to the participant’s foot width, reduces lateral sway thereby producing weaker correlation results for the ML direction. However, caution is needed in interpreting the result, as gender, demonstrating a significant between test-groups difference, may be a confounding factor.

Single Leg Stance was the only static balance test to record a significant correlation coefficient in the vertical direction for the FFT Mean frequency measure. The result supports the work by Goldie, et al. (1989) who found that the CFP vertical direction measures of postural sway were the most reliable in detecting a high level of unsteadiness during stance balance testing. The current research revealed a significant correlation coefficient for both the NW and TW dynamic balance tests in the vertical direction. One possible explanation for the latter result is that functional tests, unlike the static-based balance tests, display a high level of unsteadiness and requires a greater degree of effort to maintain stability. Together, these two vertical acceleration direction results indicate that the potential of the SP in assessing postural sway in the more challenging balance tests. Potentially the SP could be used in the clinical practice environment for assessing postural sway in more challenging static and
dynamic balance activities, which are more likely to represent everyday functional
tasks.

Although gait is a bipedal activity, all participants completed the dynamic balance
tests with only one “whole-of-foot” contact over the CFP. The FFT Mean frequency
measure results for the NW balance test did not produce a significant correlation
coefficient in either the AP or ML directions. The result suggests that the CFP may
only be useful in assessing postural sway in dynamic balance tests performed at
speeds below that of normal gait or where more than one “whole-of-foot” contact is
possible. To trial more than one “whole-of-foot” contact, a custom-design CFP with
an increased length or multiple plates would be required. A possible explanation for
the result is that the balance test of NW, is assessing a highly practiced daily task not
requiring significant cognitive focus for performance with subsequent minimal
postural sway (Woollacott & Shumway-Cook, 2002). Accordingly, until further
studies validate the use of the NW for balance test assessment by both the CFP and
SP, its use in the clinical practice environment is not supported.

The SLS and TW were the two most functionally challenging balance tests assessed
in the study and both recorded a significant correlation coefficient for the FFT Mean
frequency measure results for all three directions for both the CFP and SP. The results
provide further evidence that the SP can accurately assess postural sway when the
challenge of the balance test is increased. However, caution is required in interpreting
the results as these two balance tests are unlikely to be performed regularly in
everyday tasks. Consequently, they both require learning and become highly
cognitive demanding tasks, known to adversely influence postural sway measures
reflected as an increased postural sway area, especially in the elderly (Huxhold, et al.,
Despite this, both tests could be suitable for balance assessment by the SP in the clinical practice environment.

The frequency-domain measures of Raw Standard Deviation (RSD) of the filtered accelerations and FFT Maximum frequency records an equal number of significant correlation coefficients between the two measuring systems. In the ML and vertical directions, a significant correlation coefficient for the FFT Maximum frequency measure is only evident in the complex balance test of TW. In contrast, the frequency spectral measure of RSD in these two directions produces a significant correlation coefficient for the SLS and TW balance tests. The latter result further supports the suitability of the SP in measuring postural sway especially with increasing challenge of the balance test. Unexpectedly, the frequency spectral measure of RSD in the AP direction did not show a significant correlation coefficient for any of the assessed balance tests. However, FFT Maximum frequency measure of this direction demonstrates a significant correlation coefficient in the two most naturally “practiced” balance tests of CS and NW. The FFT Maximum frequency result supports the recommendation by Bartlett (2007), that the FFT maximum frequency is required for data analysis. The results for the SD and FFT Maximum frequency measures show the validity of the SP in the AP direction reduces with an increase in the challenge of the balance test. These results may be explained by a greater dependence on the hip rather than ankle musculature in maintaining postural stability during the more challenging balance tests (Moore, et al., 1988). Consequently, a potential increase in postural sway in the ML rather than AP direction would be noted.
For the frequency-domain measure of RMS, the only significant correlation between the CFP and SP’s measures was found in the vertical direction for the SLS balance test. The study was unable to reproduce the results of previous CFP clinical studies which reported the spectral measure of RMS to be the most reliable in detecting alterations of postural sway in clinical populations (Field, et al., 2008; Mientjes & Frank, 1999; Poole, et al., 2008). Furthermore, researchers have demonstrated that the use of the RMS frequency spectral measure in isolation during more challenging balance tests may led to a Type 2 error (false negative). This may have occurred in the present study and highlights the importance of selecting an appropriate combination of measures for postural sway analysis to detect all the altered strategies employed in maintaining balance (Dault, et al., 2001; Field, et al., 2008). In isolation, RMS is unlikely to be a valid frequency-domain measure with the SP.

If all participants’ results are combined the SP’s postural sway measures are equivalent to those of the CFP. The most valid measure for assessing postural sway was FFT mean frequency, especially in the AP direction during the more challenging SLS and TW balance tests.

The control group’s frequency spectral analysis measures mirror those of the all participants’ analysis. Again, the FFT Mean frequency measure was the most valid frequency-domain measure in all three directions as it produced the highest number of significant correlation coefficients between the CFP and SP measures. Likewise, the AP and ML directions produced significant correlation coefficients for the SLS, CS, NS and TW balance tests. Yet again, for all the balance tests the AP direction, demonstrating a stronger correlation, was the better match. These results further
confirm that the SP is equal to the CFP in measuring postural sway for both static and dynamic balance tests for the normal population.

In the *chronic neck pain group* a lower number of significant correlation coefficients were recorded for the four frequency-domain measures in all three directions compared to “all participants” and the “control group”. Also in comparison, the FFT Mean frequency measure recorded a lower number of significant correlation coefficients in all three directions, and was the most valid frequency-domain measure only in the AP direction. Significant correlation coefficients for this measure in the AP direction were recorded for the SLS, CS and TW balance tests, and t in the ML direction for the CS and NS balance tests. One possible explanation for these FFT Mean measure results may be the statistically significant difference between-test-groups for the measure of foot width. This explanation is supported by Alonso, et al. (2012) Chiari, et al. (2002), and Chou, et al. (2009) who found an increase in total stance width (directly related to the participant’s foot width) reduces lateral sway producing weaker correlations for the ML direction. However, as foot and total stance width are gender related, again caution is needed in interpreting the result in the CNP test-group, as gender may be a confounding factor in a mixed gender population. The absence of any significant correlation coefficient for the FFT Mean frequency measure in the vertical direction, means that this directional measure is a less sensitive means of detecting alterations in postural sway, confirming the findings by Rosker, et al. (2011).

Together, the FFT Mean measure results suggest that the SP is less sensitive in measuring postural sway in the clinical population of CNP, and caution is required when interpreting frequency-domain measures of postural sway in any clinical study.
Involving this population. This interpretation of these results is supported by several other researchers who found that for CNP sufferers, the most reliable axial direction in detecting postural sway disturbances using frequency spectral analysis varies according to the actual balance test performed, the applied visual and surface conditions for that balance test and the aetiology of the patient’s pathology (Field, et al., 2008; Treleaven, Murison, et al., 2005).

No previous CFP study has assessed dynamic balance tests in CNP sufferers. Therefore, it’s accepted “gold-standard” reference for measuring postural sway in this clinical population for dynamic balance tests may not be applicable. Consequently, the presence of only one significant correlation for the dynamic balance tests may relate to an inability to effectively measure postural sway by either the CFP or SP. Future investigation to determine the validity of both CFP and SP measures of postural sway during dynamic balance testing is needed.

In conclusion, for the CNP group the SP revealed a similar but weaker relationship with an increase in the challenge of the balance test, compared to the results for all participants and the control group. Therefore, the balance testing in the clinical practice environment for CNP sufferers, using the SP measures should also be limited to the AP direction for the more challenging SLS and TW balance.

2.2 Balance Tests – FFT Mean Frequency Measures between Test-Groups

Difference

As the study found the FFT Mean frequency measure to be the most valid frequency-domain measure following Pearson’s correlation analysis of the CFP and SP’s measures of postural sway results, this measure was selected to compare mean scores
for between test-groups difference analysis. Overall, the independent samples $t$-tests analyses further supports the primary aim of the study that quantitative measures of postural sway during both static and dynamic balance tests, obtained from the SP are valid when compared to those from the known “gold-standard” reference of a laboratory-grade CFP. In the AP direction neither the CFP nor the SP detected a statistically significant between test-groups difference for any of the five balance tests. This result was unexpected as the AP direction recorded the strongest bivariate Pearson’s $r$ correlation coefficient between CFP and SP’s FFT mean frequency measures for all balance tests, except tandem walking. In the ML direction the CFP recorded no statistically significant between test-groups difference for any of the five balance tests, whilst the SP recorded a statistically significant difference only for the SLS balance test. In the vertical direction the CFP recorded no statistically significant between test groups difference for any of the five balance tests, whilst the SP recorded a statistically significant difference only for the NS balance test. Since these two statistically significant independent samples $t$-tests recorded by the SP were noted for different balance tests and in different directions, they are most likely to be Type 1 errors (false positive). Another explanation for this finding is the possibility that that the study’s participants in the CNP group displayed no significant balance deficit. Overall, as the CFP and SP respectively detected none or an insignificant number of statistically significant between test-groups differences, the validity of the SP in measuring postural sway compared to the CFP is further confirmed.

The study found no statistically significant between test-groups difference for the CFP measures for any of the three static balance tests in any direction. The study revealed contradictory results to those of Alund, et al. (1993), Field, et al. (2008), Karlberg, et al. (1996), Karlberg, et al. (1995), Madeleine, et al. (2004), Michaelson, et al. (2003),
Poole, et al. (2008) and a systematic literature review by Ruhe, et al. (2011). These researchers established validity and reliability in detecting balance disturbances, in either the AP or ML directions, in patients with chronic neck pain of different aetiologies. The study’s contradictory results are unlikely to be associated with its design, since the type of static balance tests assessed and their associated characteristics of testing duration, sampling frequency, cut-off frequency, visual and surface conditions and number of allowed repetitions were suggested and used in similar research studies. Furthermore, this contradictory result is unlikely to be due to the study’s statistical power as the allocated test group’s size either matched or exceeded those of the previously cited similar clinical studies. One possible explanation relates to the BMI of the participants. Teasdale, et al. (2006), Hue, et al. (2007) and Ku, et al. (2012) have demonstrated that obesity is directly associated with an increase in postural sway during static balance testing. As the majority of participants for both test-groups here were classified as either underweight or normal, the resultant minimal postural sway during static balance testing may have contributed to a decreased likelihood of detecting a statistically significant between test-groups difference for the measures of postural sway.

As no previous study has assessed frequency-domain measures during dynamic balance testing in CNP sufferers, the importance of the absence of a statistically significant between test-groups difference for the CFP’s measures during the two dynamic balance tests assessed in the study is yet to be determined.
3. Postural Sway (FFT Mean Frequency) and Self-Rating Questionnaires (SRQ) Measures

This research employed the VAS (Pain), VAS (Stress), NDI, SF 36 and DASS-21 self-rating questionnaires to cover a range of features of the multidimensional phenomenon of CNP.

Results for both techniques for assessing postural sway indicated that the vast majority of the demonstrated Pearson’s r significant correlation coefficients between FFT Mean frequency and self-rating pain and disability measures existed for the more challenging balance tests of SLS and TW. The result again confirms that the SP measures of postural sway have the strongest correlation with the CFP measures during these more challenging balance tests. This suggests that they should be the preferred static and dynamic balance tests selected for the clinical assessment of balance using the SP.

The CFP recorded the highest number of significant correlation coefficients between FFT Mean frequency and self-rating pain and disability measures in the vertical direction and a lower but equal number in the AP and ML directions. Once again the SP produced the highest number of significant correlation coefficients in the AP direction, confirming the AP direction measure of postural sway as having the highest validity. The SP produced three times the number of significant correlation coefficients in the AP direction compared to the CFP for both test groups. The latter result may be attributed to the SP displaying greater sensitivity in detecting postural sway changes in the AP direction in participants exhibiting an overall self-perceived mental health disability when compared to the CFP. However, the possibility of the
presence of Type 1 error (false positive) results cannot be excluded. The study is unable to confirm the cause of the result and further investigation is required.

Analysis of the results for all acceleration directions and SRQ revealed that the single most consistent significant correlation coefficient was found between DASS-21 anxiety and FFT Mean frequency measures for the TW balance test. Therefore, only the DASS-21 anxiety measure is recommended for future clinical studies and practice involving CNP sufferers to examine the relationship between postural sway and self-rating of distress.

The study revealed an equal number of significant correlation coefficients exists between FFT Mean frequency and both the SF-36 physical and mental health component summary measures for both test groups as described by Ware Jr (2000), Ware Jr and Sherbourne (1992) and Ware and Gandek (1998). The result further supports the theory that chronic pain is a multidimensional construct and the need for a bio-psycho-social approach to the management of CNP sufferers. In contrast, Hughes, et al. (1996) demonstrated no relationship between postural sway and self-reported disability for the physical functioning subset of the SF 36 questionnaire. However, this study did not evaluate the relationship between postural sway and any of the other seven subsets of the SF-36 questionnaire and neither the physical or mental health component summaries were calculated. Moreover, the study by Hughes, et al. (1996) (and the majority of studies assessing the influence of psychological factors on postural sway) was restricted to the elderly, who would have biased the study’s outcome, as age and fatigue have been shown to have a direct linear relationship with postural sway.
The VAS (Stress) and NDI self-rating measures produced only one significant correlation coefficient for the control group, and none for the CNP group, for the relationship between FFT Mean Frequency and SRQ measures. As one determinant of clinical utility of these self-reporting measures is time efficiency, then the VAS (Pain), SF 36 and DASS-21 measures should be selected to assess this relationship in the clinical practice environment.

4. Self-Rating Questionnaires (SRQ) and Mechanical Pain Threshold Testing (MPTT) Measures

The study test groups produced differing patterns of significant correlation for the self-rated questionnaires & MPTT measures at the cervical spine site. VAS (Pain), NDI, SF-36 physical functioning and general health all indicated an overall component of self-perceived physical health disability for the study’s CNP group. The study indicates the need for caution when using both the SRQ and MPTT measures in clinical practice to assess the component of mental health of pain in CNP sufferers. The result is consistent with the presence of local sensory mechanical hyperalgesia reported in CNP sufferers and supports the need to adopt a bio-psycho-social approach to treatment (Chien & Sterling, 2010). Furthermore, the presence of significant Pearson’s r correlation coefficients for NDI and SF-36 general health measures at the asymptomatic remote site further emphasises the component of self-perceived physical health disability. The latter result may reflect the influence of “central hyperexcitability” on the CNP participant’s physical functioning. The current study’s finding is supported by Petzke, et al. (2003) and Sterling, Treleaven, Edwards, and Jull (2002) who reported that increased pain sensitivity (both sensory and affective) is not a response bias to psychological factors but is correlated with “central
hyperexcitability”. In contrast, the significant correlation coefficients between VAS (Stress), NDI, SF-36 social functioning and DASS-21 anxiety measures with the MPTT measures indicated an overall component of self-perceived mental health disability for the study’s control group. The result may reflect the ever increasing impact of mental health illness within the Australian population (AIHW; 2013).

Obesity has been shown to be directly associated with greater pain-related disability, depression and reduced quality of life for physical function in the absence of other chronic medical conditions (Doll, et al., 2012; Marcus, 2004; McCarthy, et al., 2008). Accordingly, the presence and strength of any Pearson’s $r$ correlation results between self-rated questionnaires & MPTT measures may have been influenced by the study’s population not being representative of the general population for the scale measure of BMI.

5. Postural Sway (FFT Mean Frequency) and Mechanical Pain Threshold Testing (MPTT) Measures

No prior study has assessed the relationship between postural sway and MPTT measures in CNP patients. For the CFP, a significant correlation coefficient was detected only in the vertical direction for the challenging balance test of TW for the chronic neck pain group at the cervical spine site. In contrast, the SP produced significant correlation coefficients in both the AP and vertical directions for the only other challenging SLS balance test for the CNP group at the cervical spine site. Furthermore, the SP produced a significant correlation coefficient in the AP and ML directions for different balance test for the control group, but only at the asymptomatic remote site. The results mirror the FFT Mean frequency bivariate
Pearson’s correlation analysis results, that the SP is most effective in assessing postural sway in the AP direction during the more challenging balance tests for both test-groups. The results of this relationship supports that the use of the SP in the clinical practice environment should be limited to these more challenging static and dynamic balance tests, especially in a non-clinical population.

For the CNP group the demonstrated significant correlation coefficients with the MPTT measure at the cervical spine for both CFP and SP assessment of postural sway would be expected, due to the presence of local sensory mechanical hyperalgesia. However, the two significant correlation coefficients for the SP measures at the asymptomatic remote site in the control group in different directions and using different balance tests are most likely to be Type 1 error (false positive) results.

Overall, as the SP, like the CFP, did not produce significant correlation coefficients between postural sway and MPTT measures, this supports the validity of the SP in measuring sway in both test-groups. Further research is warranted to detect the strength of the relationship between the pressure algometry and postural sway measures in the healthy to establish population norms required for future research and clinical practice. In addition, further work could confirm our understanding of the mechanisms involved in the disturbances to the sensorimotor control system and thereby improve treatment interventions for CNP sufferers.

**6. Between Test-Groups Analyses**

The study found statistically significant between test-groups mean differences for several demographic and anthropometric factors. Few studies involving balance
assessments in CNP sufferers have reported on demographic or anthropometrical measures.

The measures of gender, occupation and duration and origin of symptoms demonstrated a statistically significant difference between the control and CNP groups. Currently, the influence of these measures on postural sway is unknown and further research is required to fully understand their significance. The research presented here confirms the results of previous studies that CNP and mean MPPTs measures demonstrate significant gender differences. This may potentially produce systematic error in assessment protocols where this is not controlled for, and thereby require caution when interpreting results (Andersson, et al., 1993; Chesterton, et al., 2003; Côté, et al., 1998; Côté, et al., 2004; Fejer, et al., 2006; Fillingim, et al., 2000; Guez, et al., 2002; Hogg-Johnson, et al., 2008; Rivest, et al., 2010).

As expected, the study showed no significant difference for the number of prescribed medication(s), and the effects of medication were minimized by requesting participants to cease medication 24 hours before testing.

Foot width was the only physical measure to display a statistically significant difference between the control and CNP groups, and is known to affect the size of an individual’s base-of-support and consequently their postural sway. No study has investigated the association between foot width or size and the presence and / or severity of chronic neck pain. The statistically significant difference for the measure of foot width is most likely directly attributed to the earlier reported statistical difference between test-groups for the measure of gender.
The study found no significant between test-groups difference for height, although it has been documented as the most influential anthropometric measure affecting balance (Alonso, et al., 2012). Normalisation of postural sway measures for the anthropometric measure of weight is common practice, but it is rare for the measure of height to be factored in to study protocols. To fully understand the influence of height on postural sway measures, normalisation of the collected data for the participant’s height would need to become a common practice. Furthermore, only three balance assessment studies involving CNP sufferers have recorded anthropometric measures, including height. To ensure all possible confounders are considered, all future balance assessment studies involving CNP sufferers should record and report height and other anthropometric measures, as a standard protocol to facilitate analyses of a study’s results data and comparison between related research studies.

BMI measures indicated that only two participants in the study were classified as obese (BMI ≥ 30.0 Kg/m²) and eleven as overweight (BMI 25.0 – 29.9 Kg/m²). The BMI findings for the study are not be a true representation of the obesity rate of the general population, and may have influenced the likelihood of a statistically significant between test-groups difference for the physical measures of weight and BMI. The presence of a type 2 error (false negative) result may exist, and must be identified, as both chronic pain and postural sway have been reported to be influenced by obesity. A larger sample size is required to clarify the influence of BMI on the study’s results.

The VAS (Pain) and NDI questionnaires demonstrated a statistically significant difference between the control and CNP groups. These results for CNP sufferers are
supported extensively by the research literature (Field, et al., 2008; Karlberg, et al., 1996; Poole, et al., 2008; Röijezon, et al., 2011; Scott, et al., 2005; Stewart, Maher, Refshauge, Bogduk, et al., 2007; Treleaven, Jull, et al., 2005b). However, the VAS (Stress) measure results showed no significant difference between the control and chronic neck pain groups and the study was unable to reproduce the findings of Price, et al. (1987).

The study noted a lack of a significant between test-groups difference for the DASS-21 measure, confirming the absence of a significant mental health component summary measure. As only one other study employed this measure in a clinical study involving CNP patients (Stewart, Maher, Refshauge, Herbert, et al., 2007), additional research is required to confirm the suitability of this measure in clinical studies involving CNP sufferers. Together, the VAS (Stress) and DASS-21 results indicated the CNP participants were no more stressed than the control participants at the time of testing, and consequently the between test-groups differences for the postural sway and MPTT measures were not attributed to their current levels of stress.

The study indicated a strong significant between test-groups difference for the SF-36 physical function, role limitation – physical health, energy / fatigue (vitality), bodily pain and general health sub-scale measures. All these sub-scales, except vitality, are combined to produce a physical health component summary measure, and a strong significant between test-groups’ difference, highlights the self-rated physical disability of the CNP participants.

An overall analysis of the SRQ measures results (a significant difference between the control and CNP groups for VAS (Pain), NDI and SF-36 (physical health component
summary measure)) indicate that the study’s CNP sufferers had predominantly a low self-rated physical health component limitation of pain and disability or that the mental health component of pain and disability was underestimated. The employment of these three measures for assessment of self-rating pain and disability involving CNP sufferers is supported.

A significant difference between the test-groups was found to exist for both the cervical spine and asymptomatic remote sites MPTT measures, thereby confirming the presence of sensory mechanical hyperalgesia in the CNP patients. These results have also been established by other researchers, with a range of theories having been advanced to explain the phenomenon (Chien & Sterling, 2010; McLean, et al., 2005; Sterling, Hendrikz, & Kenardy, 2011; Walton, Macdermid, Nielson, Teasell, Chiasson, et al., 2011; Walton, MacDermid, Nielson, Teasell, Reese, et al., 2011). Accordingly, the continued use of pressure algometry for the detection of mechanical pain thresholds for both research and clinical practice is recommended.

7. Limitations of the Study

Three possible limitations of the study require reporting. Firstly, random accelerometer signal noise extraneous to the human body accelerations can result from movement and/or vibration inherently present at the interfaces between the SP, the SPIbelt and the participant. Although, filtering (0 – 12 Hz) during data processing reduces this effect, it cannot be fully eliminated. This limitation must be acknowledged, but is inherent in all balance studies using wearable accelerometers and it may account for “outlier” results. Secondly, Nardone, Tarantola, Giordano, and Schieppati (1997) and Davidson, Madigan, and Nussbaum (2004) reported that the
The effect of fatigue on postural sway is moderate in extent, primarily involving the musculature of the lumbar spine, hip and knee joint complexes and is short-lasting. The possibility of fatigue influencing postural sway should be considered when performing repeated balance testing at a specific time on a single day, especially for elderly participants. Even though the study visually monitored participants for signs of fatigue and provided a recovery period if required, the possible effects of fatigue on postural sway cannot be wholly excluded. A self-rating questionnaire assessing the level of fatigue would assist in determining the influence of fatigue during the balance testing protocols. Furthermore, the study design employed randomisation of the balance testing order to minimise this effect. Thirdly, the exclusion of participants with co-existing medical conditions known to affect balance resulted in a population not truly representative of the general population. Consequently, caution must be shown in interpreting the results and establishing generalisations from the current study.

Finally, the main delimitation of the study was that BMI of both test groups was lower than the general population. The mean Australian BMI for males and females are respectively 27.6 and 26.4 (category – overweight), whilst the mean BMI for the control and CNP groups in the study were respectively 23.71 and 24.88 (category – normal). Consequently, the study’s participants were not truly representative of the general population and caution must be shown in interpreting the results and establishing generalisations from the current study.
8. Implications for Clinical Practice

Considerable clinical evidence exists for the presence of balance disturbances, demonstrated by altered postural sway, in patients suffering from a wide range of orthopaedic, sports, neurological, geriatric and paediatric conditions. The quantitative assessment of postural sway by the SP, during both static and dynamic balance tests in the clinical practice environment could create a valuable clinical assessment and feedback tool of balance. The significant benefits of such a tool include early detection and better on-going monitoring of postural sway in pathological conditions and the immediate assessment and feedback of treatment interventions possibly leading to improved rehabilitation outcomes for patients experiencing balance disturbances. In turn, these benefits could result in a reduction in the likelihood of falls-related injuries and potentially provide a measure of general “well-being” (both physical and behavioural). It is widely-accepted in rehabilitation medicine that proprioceptive re-training following lower limb injury is vital. However, the assessment and management of abnormal sensorimotor control resulting in balance disturbances in CNP patients is often overlooked. The results of the study contribute to the growing awareness for the need to include treatment interventions for balance disturbances in the management of CNP sufferers.

Sibley, et al. (2013) found seventy-nine per cent of physiotherapists surveyed admitted that due to the actual time required for the clinical testing of balance, uncertainty of the accuracy of the obtained results and a lack of knowledge to correctly interpret these results, a need to improve their clinical assessment of balance was necessary. This important clinical need may be addressed by the SP which is a
time efficient, portable and easily accessible tool for assessing balance by producing validated quantitative measures of postural sway.

The SP demonstrates a greater functionality, and thus potentially enhanced clinical utility, than the CFP in detecting the relationship between postural sway and self-rating pain and disability measures. This relationship is best demonstrated by the DASS-21 questionnaire and the more challenging balance tests, and consequently the DASS-21 questionnaire is recommended for clinical research and practice. The relationship between the various self-rating of pain and disability and MPTT measures is confirmed, and consequently should be clinically applied, for the physical health component in CNP sufferers.

By gathering postural sway normative data by assessing balance employing the SP, balance assessment could play a valuable role in preventative medicine. Potential roles could include the early detection of previously unidentified balance disturbances associated with a range of co-existing chronic medical conditions, for example labile anxiety mood states, or predicting the likelihood of sustaining a falls-related injury in aged or sedentary workers. Continuous measuring of postural sway during every day functional activities of healthy individuals by the SP may provide an assessment of the individual’s functional physical health over time. Likewise, the SP would also play a valuable role in the screening and on-going monitoring of an athlete’s balance assisting in optimising physical performance, reliably determining suitability to return to sport and potentially reducing the incidence of falls-related injuries. Using the SP’s wireless internet connection capabilities it is also possible to perform large scale community-based preventative assessment, monitoring and education / training programs. Improved participation and adherence to any clinical research studies
involving the assessment of balance would result from the high accessibility and low cost of the SP’s technique of measuring postural sway. Consequently, the resultant larger sample size would produce an increase in the statistical power for the trial. Lastly, the SPs assessment and on-going monitoring of postural sway would provide workers compensation and third party insurers and lawyers, a valuable quantitative measure of the changes in postural sway associated with a treatment intervention or rehabilitation program for sufferers with balance disturbances following injury or disease, and thereby justifying their associated costs.

9. Directions for Future Research

This pilot work, having confirmed the validity of the SP’s frequency-domain postural sway measures, demonstrates that future research is required to examine the test re-test reliability of these measures compared to those of the “gold-standard” reference of a laboratory-grade CFP in CNP sufferers. In addition, a repeat criterion validity study for the SP with a different sample for the CNP group is justified to confirm that the SP can discriminate between healthy individuals and those experiencing altered balance. The research could simultaneously evaluate the effectiveness for clinical treatment interventions for balance disturbances arising from CNP and other medical conditions using the SP. Furthermore, examination of the validity of the SP’s postural sway measures in other clinical populations, especially those experiencing acute conditions, is warranted. To value-add to the SP as a clinical assessment and feedback tool, the development of an algorithm (App) providing immediate data analysis of the frequency-domain measures of postural sway is justified.
In clinical practice, an individual’s scores of postural sway could be contrasted against the population norms once a sufficient data bank has been established. This method of results analysis has been used for assessing postural sway measures obtained from the Swaymeter (Lord, Menz, & Tiedemann, 2003) and could be extended for the SP. Finally, as the anthropometric measures of foot width and size and height are known to directly influence balance disturbances as measured by postural sway, it is recommended that for future comparative analysis of research studies involving balance assessment a standard protocol of recording participants’ anthropometric measures incorporating foot width be established.

10. Conclusions

This research contributes to the field of clinical balance assessment by confirming the validity of the SP quantitative measures of postural sway, relative to the laboratory-grade CFP, during both static and dynamic (functional) balance testing for the general population, and in the AP direction for the more challenging SLS and TW balance tests in CNP sufferers. The finding has not been previously reported in the literature. Following a repeat study the SP quantitative measures of postural sway may potentially overcome the tester bias and poor intra- and inter-tester reliability associated with these measures obtained from the current observational clinical balance tests, and the low accessibility and high equipment purchase costs associated with the laboratory-grade CFP. The SP potentially becomes an accurate, portable, unobtrusive, inexpensive, time efficient, and easily accessible technique for quantitatively measuring postural sway suitable for the clinical practice environment. The potential benefits are earlier detection and better on-going monitoring of postural sway changes and the immediate assessment of treatment interventions leading to
improved rehabilitation outcomes and possibly a reduction in the likelihood of falls-related injuries in CNP sufferers from balance disturbances. Potentially these benefits could also apply to sufferers experiencing balance disturbances arising from other orthopaedic, sports, neurological, geriatric or paediatric conditions.

The SP demonstrates a greater efficacy than the CFP in detecting the relationship between postural sway and self-rating pain and disability measures. The relationship between the various self-rating of pain and disability and MPTT measures are only demonstrated for the physical health summary component in CNP sufferers. Accordingly, the VAS (Pain), NDI and SF-36 (physical functioning and general health sub-scales) SRQs are most appropriate for testing this relationship in the clinical practice environment. Lastly, knowledge of the relationships between the postural sway, SRQ and MPTT measures could enhance our understanding of the mechanisms underlying the disturbances to the sensorimotor control system, improve treatment interventions and reduce the associated socio-economic burden for CNP sufferers.
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APPENDIX 1

Participant Information Form

RESEARCH PROJECT TITLE:

“SMART PHONE ASSESSMENT OF POSTURAL SWAY IN CHRONIC NECK PAIN SUFFERERS”

Researchers

The following researchers are involved in this research project:

- Mr. Adrian Rumore, Faculty of Health, University of Canberra Australia
- Professor Gordon Waddington, Faculty of Health, University of Canberra Australia
- Dr Stuart Cathcart, Faculty of Health, University of Canberra Australia

Project Aim

The aims of this research project are to assess the reliability of data obtained from a balance assessment device – Smart Phone, worn whilst standing and walking compared to the “standard” balance testing device in individuals with and without neck pain.

Background

Currently, no clinically proven wearable balance assessment device is available to provide continuous feedback to an individual whilst undertaking normal activities of daily living and general physical or sporting performances. The development of an effective wearable balance assessment device could be used in circumstances where an early warning of a change in balance could benefit the user and prevent injury, or provide ongoing information to the user about their current balance status that would assist in recovering normal movement function as part of a rehabilitation program.

Benefits of the Project

This research contributes to the development of a treatment protocol where a wearable balance assessment device can be used to provide an early and/or on-going warning about a change in balance status that would benefit the user.

General Outline of the Project

The study aims to assess the validity of a wearable balance assessment device in detecting changes in balance whilst standing and walking compared to the "standard" balance testing device in individuals with and without neck pain.

Participant Involvement

An invitation to participate in this research project has been extended via the University of Canberra bulletin boards, the University’s Faculty of Health Clinics notice boards, and notices issued to ACT Plaintiff Lawyers Association, ACT Registered Physiotherapists and Medical Practitioners.

You will be familiarized with the protocol prior to commencing.
A researcher will take your personal and medical history, and assess your suitability to participate in this research project. You will then be asked to complete questionnaires describing your neck pain (if appropriate) and psychosocial status.

If you feel distressed by any of these questions immediately contact a counselor at the University of Canberra Health and Counseling Centre - contact number (02) 6201 2351 or the ACT Mental Health Crisis Team - contact number 1800 629 354.

You will then be asked to wear a balance assessment device, the size of a mobile phone, on the outer side of your hip whilst undertaking the following five tests:

1. Stepping onto a target on the floor and balancing on your dominant leg for 30 seconds.
2. Stepping onto the target on the floor with feet comfortably apart and holding for 30 seconds.
3. Again stepping onto the target with feet together and holding for 30 seconds.
4. Walking 5 meters along a marked track on the floor and
5. Walking “Heel to Toe” for 5 meters on the track.

Up to five attempts will be allowed to successfully complete each of these balance tests with a thirty-second rest interval in between, if required. You will be required to attend the testing, once only, for a total of approximately forty-five minutes.

The risk of physical injury from participating in this project is minimal, as you are simply required to complete a series of physical activities that are often undertaken during normal daily living. In the event of an injury being sustained you will be referred to registered medical practitioner at the University of Canberra Health and Counseling Centre - contact number (02) 6201 2351 or the A & E Department at the Calvary Public Hospital. In the highly unlikely event of a serious injury 000 will be contacted immediately.

Data and Privacy

Data files will be coded so that you cannot be identified. Only the researchers will have access to the original data. All paper records will be stored under lock and key, and electronic data will be stored on a password-protected computer. Both forms of data will be stored at the University of Canberra for 5 years from the completion date of this research project, after that the data will be deleted or shredded. Your name will not be recorded in any scientific publication.

Ethics Committee Clearance

This project has been approved by the Committee for Ethics in Human Research of the University of Canberra, Project Number CEHR 11 - 106

Queries and Concerns

You have the right at any time to ask questions about any aspect of this research project. You also have the right to withdraw from this research project at any time.

If you require any further information or have any concerns following your participation in this research project do not hesitate to contact the research project supervisor: Professor Gordon Waddington - Telephone (02) 6201 2737

Participation

Thank you for agreeing to become a participant in this research project. Your time and effort are much appreciated.

Mr. Adrian Rumore
Telephone 0478 167 104
Email: ajrumore@grapevine.com.au
University of Canberra Informed Consent Form

RESEARCH PROJECT TITLE:

“SMART PHONE ASSESSMENT OF POSTURAL SWAY IN CHRONIC NECK PAIN SUFFERERS”

The clinical research project and my involvement have been clearly defined and fully explained to me. I have understood the given explanation. A copy of the research project procedures and description of any risks (both physical and psychological) have been provided to me by a “Research Project Participant Information Form”. I have read and understood this form and agree to the following:
• I am participating in the research project of my own free will and I have not been coerced in anyway to participate.
• I understand that I am free and able to withdraw consent and discontinue participation in the research project at any time.
• I have been given the opportunity to ask any questions and all such questions have been answered to my satisfaction.
• I understand that data about my personal details, physical and psychosocial status will be collected.
• I understand that any data collected will remain confidential.

If I have any further questions or queries about this research project, now or during my participation, I can contact this research project supervisor - Professor Gordon Waddington on 6201 2737.

I will allow the researchers to take my picture / video footage.

Circle one: YES / NO Initial: _____

Signature of participant: _______________________________ Date: ___/___/___

I, the undersigned, was present when the study was explained to the participant in detail and to the best of my knowledge it was understood.

Signature of researcher: _______________________________ Date: ___/___/___

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# Participant Personal Information Form

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APPENDIX 4

Participants Group Allocation Summary Form

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APPENDIX 5

Participants Recruitment Form – Control Group

PARTICIPANTS REQUIRED FOR A RESEARCH PROJECT ON “SMART PHONE ASSESSMENT OF POSTURAL SWAY IN CHRONIC NECK PAIN SUFFERERS”

We are looking for people who have experienced neck pain for longer than three months (as well as those without a history of neck pain) to test if your balance has been affected whilst standing and walking.

If you fill the following criteria you would be eligible to participate:

1. Are you over the age of 18?
2. Beside your neck, no history of major joint or nerve injury and / or disease that limits your everyday activities?

What’s involved?
You will be asked to complete a personal history form and selected questionnaires describing your experience of neck pain and your psychosocial status.

You will then need to wear an iPod touch, storing a balance assessment program, over the outer side your hip whilst undertaking the following five activities:

1. Stepping onto a target on the floor and balancing on your dominant leg for 30 seconds.
2. Stepping onto the target on the floor with feet comfortably apart and holding for 30 seconds.
3. Again stepping onto the target with feet together and holding for 30 seconds.
4. Walking 5 meters along a marked track on the floor and
5. Walking “Heel to Toe” for 5 meters on the track.

The risk of an unforeseen event / injury in this research project is the same as what you would expect to experience in normal daily living, as this project requires that you complete physical activities that are undertaken during normal daily living.

When?
Anytime from 8:00 am to 8:00 pm from March 2012.

Testing duration?
YOU WILL BE REQUIRED TO ATTEND FOR TESTING ONCE ONLY FOR A PERIOD OF APPROXIMATELY FORTY - FIVE MINUTES.

Are you available to Participate?
If you are available to become a participant in this research project please contact:

Mr Adrian Rumore
Mobile phone: 0478 167 104 (Text)
Email: ajrumore@grapevine.com.au
APPENDIX 6

Participants Recruitment Form – Chronic Neck Pain Group

REQUEST FOR RESEARCH PARTICIPANTS

Dear Colleague,

We are currently undertaking a research project at the University of Canberra titled - “Smart Phone assessment of postural sway in chronic neck pain sufferers”.

We are looking for participants who have experienced neck pain for longer than three months to test the influence of the neck pain on their balance during basic standing and walking tasks.

We would very much appreciated your support for this research project and ask if you could display the attached leaflet on your practice notice board or directly recommend suitable patients.

We will notify you of our research project results when they become available.

Thanking you in advance for your time and consideration.

Yours sincerely,

Mr. Adrian Rumore,
Professor Gordon Waddington &
Dr Stuart Cathcart,
Faculty of Health,
University of Canberra

Date: February 14, 2012
PARTICIPANTS REQUIRED FOR A RESEARCH PROJECT ON “SMART PHONE ASSESSMENT OF POSTURAL SWAY IN CHRONIC NECK PAIN SUFFERERS”

We are looking for people who have experienced neck pain for longer than three months (as well as those without a history of neck pain) to test if your balance has been affected whilst standing and walking.

If you fill the following criteria you would be eligible to participate:

1. Are you over the age of 18?
2. Beside your neck, no history of major joint or nerve injury and / or disease that limits your everyday activities?

What’s involved?
You will be asked to complete a personal history form and selected questionnaires describing your experience of neck pain and your psychosocial status.

You will then need to wear an iPod touch, storing a balance assessment program, over the outer side of your hip whilst undertaking the following five activities;
1. Stepping onto a target on the floor and balancing on your dominant leg for 30 seconds.
2. Stepping onto the target on the floor with feet comfortably apart and holding for 30 seconds.
3. Again stepping onto the target with feet together and holding for 30 seconds.
4. Walking 5 meters along a marked track on the floor and
5. Walking “Heel to Toe” for 5 meters on the track.

The risk of an unforeseen event / injury in this research project is the same as what you would expect to experience in normal daily living, as this project requires that you complete physical activities that are undertaken during normal daily living.

When?
Anytime from 8:00 am to 8:00 pm from March 2012.

Testing duration?
YOU WILL BE REQUIRED TO ATTEND FOR TESTING ONCE ONLY FOR A PERIOD OF APPROXIMATELY FORTY - FIVE MINUTES.

Are you available to Participate?
If you are available to become a participant in this research project please contact:

Mr Adrian Rumore
Mobile phone: 0478 167 104 (Text)
Email: ajrumore@grapevine.com.au
Dear [Blank],

Thank you for your agreeing to participate in our research project - “Smart Phone assessment of postural sway in chronic neck pain sufferers”.

We wish to confirm that your appointment is [Date].

Please note that you will be met at the Reception Area of the University of Canberra Faculty Of Health Clinics located at Building 12, Level B, Room 40. For your reference the University of Canberra Campus Map link is http://www.canberra.edu.au/maps.

For your participation in this research project it would be most suitable to wear “gym gear”- shorts and tops only, as you will need to be barefoot during the actual testing. If required, nearby change rooms will be made available. Also if appropriate, you will need to bring your reading glasses to complete the required forms and questionnaires.

Try to get a normal night’s sleep the night before the day of testing, and finally you are ask to refrain from taking pain relief medication or consuming alcohol 24 hours prior to testing as these products may influence your balance. If you are unable to attend this appointment please contact:

Mr. Adrian Rumore  
Telephone 0478 167 104  
Email: ajrumore@grapevine.com.au

Yours sincerely,

Mr. Adrian Rumore,  
Professor Gordon Waddington &  
Dr Stuart Cathcart,  
Faculty of Health,  
University of Canberra

Date:
APPENDIX 8

UC Research Project No 11-106. Independent Complaints Contact Letter

PROJECT INFORMATION

The following study has been reviewed and approved by the University of Canberra's Committee for Ethics in Human Research.

<table>
<thead>
<tr>
<th>Project title:</th>
<th>&quot;Influence of neck pain on postural sway&quot;</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Project number:</th>
<th>Principal researcher:</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-106</td>
<td>Prof Gordon Waddington</td>
</tr>
</tbody>
</table>

INDEPENDENT COMPLAINTS PROCEDURE

1. As a participant or potential participant in research, you will have received written information about the research project. If you have questions or problems which are not answered in the information you have been given, you should consult the researcher or (if the researcher is a student) the research supervisor. For this project, the appropriate person is:

   Name:                Prof Gordon Waddington
   Contact details:     Faculty of Health
                        University of Canberra
                        Ph: 02 6201 2737

2. If you wish to discuss with an independent person a complaint relating to:
   - conduct of the project, or
   - your rights as a participant, or
   - University policy on research involving human participants,

Please Contact:

   Ethics and Compliance Officer
   Telephone (02) 6201 8740
   Room 1D 98
   UNIVERSITY OF CANBERRA ACT 2601

Providing research participants with this information is a requirement of the National Health and Medical Research Council National Statement on Ethical Conduct in Research Involving Humans, which applies to all research with human participants conducted in Australia.

Further information on University of Canberra research policy is available in University of Canberra Guidelines for Responsible Practice in Research and Dealing with Problems of Research Misconduct and the Committee for Ethics in Human Research Human Ethics Manual. These documents are available from the Research Services Office at the above address or on the University's web site at https://sgrd.canberra.edu.au/policy/policy.php?pol_id=5136 (Research Guidelines)

APPENDIX 9

“Thank You for Participating” Letter Form

Dear

We wish to thank you for your recent participation in our research project - “Smart Phone assessment of postural sway in chronic neck pain sufferers”.

Your time and effort were very much appreciated, and without your support this research project could not have been completed.

We will notify you of our research project results when they become available.

Yours sincerely,

Mr. Adrian Rumore,
Professor Gordon Waddington &
Dr Stuart Cathcart,
Faculty of Health,
University of Canberra

Date:
# APPENDIX 10

## Participant Demographic & History Data Form

<table>
<thead>
<tr>
<th>PARTICIPANT NAME:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DEMOGRAPHIC DATA:</strong></td>
<td></td>
</tr>
<tr>
<td>AGE (YEARS):</td>
<td></td>
</tr>
<tr>
<td>GENDER (M / F):</td>
<td></td>
</tr>
<tr>
<td>OCCUPATION:</td>
<td></td>
</tr>
<tr>
<td>REFERRAL BASIS:</td>
<td></td>
</tr>
</tbody>
</table>

## HISTORY OF SYMPTOMS:

| DURATION OF NECK PAIN / SYMPTOMS (YEARS): |  |
| ORIGIN OF SYMPTOMS: (TRAUMA OR INSIDIOUS (NON – TRAUMATIC)) |  |
| CURRENT PRESCRIBED MEDICATION (S): |  |

<table>
<thead>
<tr>
<th>DO YOU HAVE (OR HAD) ANY OF THE FOLLOWING MEDICAL CONDITIONS:</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. HISTORY OF SYSTEMIC RHEUMATIC OR NEUROLOGICAL DISEASE (S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. UNEXPLAINED LOSS OF CONSCIOUSNESS IN THE PAST YEAR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. VESTIBULAR PATHOLOGY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. MAJOR VISUAL OR HEARING DEFICITS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. DIABETES (TYPE 1 OR 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. UNCONTROLLED ABNORMAL BLOOD PRESSURE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. SPINAL FRACTURE AND /OR DISLOCATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. PRIOR SPINAL SURGERY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. MAJOR JOINT OR NERVE INJURY, ESPECIALLY OF THE LOWER LIMBS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. DIAGNOSED PSYCHIATRIC DISORDER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. PRESCRIBED MEDICATION KNOWN TO INFLUENCE BALANCE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| CODE NUMBER: | DATE: |
APPENDIX 11

Body Chart Form

ON THE BODY CHARTS BELOW PLEASE MARK WHERE YOU ARE EXPERIENCING PAIN OR OTHER SYMPTOMS RIGHT NOW.

CODE NUMBER:          DATE:
APPENDIX 12

VAS Pain Questionnaire Form

Please rate how “INTENSE YOUR PAIN IS RIGHT NOW” by placing a mark along the line between 0 and 10.

NO PAIN AT ALL

WORST IMAGINABLE PAIN

CODE NUMBER:  DATE:
APPENDIX 13

VAS Stress Questionnaire Form

Please rate how “STRESSED BY YOUR PAIN DO YOU FEEL RIGHT NOW” by placing a mark along the line between 0 and 10.

0         1         2         3         4         5         6         7         8         9         10

NOT STRESSED AT ALL                    EXTREMELY STRESSED

CODE NUMBER: DATE:
APPENDIX 14
Neck Disability Index Questionnaire

Please answer each section by circling the **ONE CHOICE THAT MOST APPLIES TO YOU RIGHT NOW.**

**SECTION 1--Pain Intensity**
A. I have no pain at the moment  
B. The pain is mild at the moment.  
C. The pain comes and goes and is moderate.  
D. The pain is moderate but does not vary much.  
E. The pain is severe but comes and goes.  
F. The pain is severe but does not vary much.

**SECTION 2-- Personal Care (Washing, Dressing etc.)**
A. I can look after myself without causing extra pain.  
B. I can look after myself normally but it causes extra pain.  
C. It is painful to look after myself and I am slow and careful.  
D. I need some help, but manage most of my personal care.  
E. I need help every day in most aspects of self-care.  
F. I do not get dressed; I wash with difficulty and stay in bed.

**SECTION 3--Lifting**
A. I can lift heavy weights without extra pain.  
B. I can lift heavy weights, but it causes extra pain.  
C. Pain prevents me from lifting heavy weights off the floor but I can if they are conveniently positioned, for example on a table.  
D. Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned.  
E. I can lift very light weights.  
F. I cannot lift or carry anything at all.

**SECTION 4 --Reading**
A. I can read as much as I want to with no pain in my neck.  
B. I can read as much as I want with slight pain in my neck.  
C. I can read as much as I want with moderate pain in my neck.  
D. I cannot read as much as I want because of moderate pain in my neck.  
E. I cannot read as much as I want because of severe pain in my neck.  
F. I cannot read at all.

**SECTION 5--Headache**
A. I have no headaches at all.  
B. I have slight headaches, which come infrequently.  
C. I have moderate headaches, which come infrequently.  
D. I have moderate headaches, which come frequently.  
E. I have severe headaches, which come frequently.  
F. I have headaches almost all the time.
SECTION 6 -- Concentration
A. I can concentrate fully when I want to with no difficulty.
B. I can concentrate fully when I want to with slight difficulty.
C. I have a fair degree of difficulty in concentrating when I want to.
D. I have a lot of difficulty in concentrating when I want to.
E. I have a great deal of difficulty in concentrating when I want to.
F. I cannot concentrate at all.

SECTION 7--Work
A. I can do as much work as I want to.
B. I can only do my usual work, but no more.
C. I can do most of my usual work, but no more.
D. I cannot do my usual work.
E. I can hardly do any work at all.
F. I cannot do any work at all.

SECTION 8--Driving
A. I can drive my car without neck pain.
B. I can drive my car as long as I want with slight pain in my neck.
C. I can drive my car as long as I want with moderate pain in my neck.
D. I cannot drive my car as long as I want because of moderate pain in my neck.
E. I can hardly drive my car at all because of severe pain in my neck.
F. I cannot drive my car at all.

SECTION 9--Sleeping
A. I have no trouble sleeping
B. My sleep is slightly disturbed (less than 1 hour sleepless).
C. My sleep is mildly disturbed (1-2 hours sleepless).
D. My sleep is moderately disturbed (2-3 hours sleepless).
E. My sleep is greatly disturbed (3-5 hours sleepless).
F. My sleep is completely disturbed (5-7 hours sleepless).

SECTION 10--Recreation
A. I am able engage in all recreational activities with no pain in my neck at all.
B. I am able engage in all recreational activities with some pain in my neck.
C. I am able engage in most, but not all recreational activities because of pain in my neck.
D. I am able engage in a few of my usual recreational activities because of pain in my neck.
E. I can hardly do any recreational activities because of pain in my neck.
F. I cannot do any recreational activities all.
DISABILITY INDEX NET SCORE:


DISABILITY INDEX % SCORE:


CODE NUMBER: DATE:
1. In general, would you say your health is:

<table>
<thead>
<tr>
<th>Choice</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>1</td>
</tr>
<tr>
<td>Very good</td>
<td>2</td>
</tr>
<tr>
<td>Good</td>
<td>3</td>
</tr>
<tr>
<td>Fair</td>
<td>4</td>
</tr>
<tr>
<td>Poor</td>
<td>5</td>
</tr>
</tbody>
</table>

2. Compared to one year ago, how would you rate your health in general now?

<table>
<thead>
<tr>
<th>Choice</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Much better now than one year ago</td>
<td>1</td>
</tr>
<tr>
<td>Somewhat better now than one year ago</td>
<td>2</td>
</tr>
<tr>
<td>About the same</td>
<td>3</td>
</tr>
<tr>
<td>Somewhat worse now than one year ago</td>
<td>4</td>
</tr>
<tr>
<td>Much worse now than one year ago</td>
<td>5</td>
</tr>
</tbody>
</table>
The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, by how much?

(Circle One Number on Each Line)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Yes, Limited a Lot</th>
<th>Yes, Limited a Little</th>
<th>No, Not limited at All</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>4. Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>5. Lifting or carrying groceries</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>6. Climbing several flights of stairs</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>7. Climbing one flight of stairs</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>8. Bending, kneeling, or stooping</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>9. Walking more than a mile</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>10. Walking several blocks</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>11. Walking one block</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>12. Bathing or dressing yourself</td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
</tbody>
</table>
During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of your physical health**?

(Circle One Number on Each Line)

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>13. Cut down the amount of time you spent on work or other activities</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>14. <strong>Accomplished less</strong> than you would like</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>15. Were limited in the <strong>kind</strong> of work or other activities</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>16. <strong>Had difficulty</strong> performing the work or other activities (for example, it took extra effort)</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of any emotional problems** (such as feeling depressed or anxious)?

(Circle One Number on Each Line)

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Cut down the <strong>amount of time</strong> you spent on work or other activities</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>18. <strong>Accomplished less</strong> than you would like</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>19. Didn't do work or other activities as <strong>carefully</strong> as usual</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
20. During the **past 4 weeks**, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

(Circle One Number)

- Not at all 1
- Slightly 2
- Moderately 3
- Quite a bit 4
- Extremely 5

21. How much **bodily** pain have you had during the **past 4 weeks**?

(Circle One Number)

- None 1
- Very mild 2
- Mild 3
- Moderate 4
- Severe 5
- Very severe 6

22. During the **past 4 weeks**, how much did **pain** interfere with your normal work (including both work outside the home and housework)?

(Circle One Number)

- Not at all 1
- A little bit 2
- Moderately 3
- Quite a bit 4
- Extremely 5

These questions are about how you feel and how things have been with you **during the past 4 weeks**. For each question, please give the one answer that comes closest to the way you have been feeling.
How much of the time during the past 4 weeks . . .

(Circle One Number on Each Line)

<table>
<thead>
<tr>
<th>Q</th>
<th>All of the Time</th>
<th>Most of the Time</th>
<th>A Good Bit of the Time</th>
<th>Some of the Time</th>
<th>A Little of the Time</th>
<th>None of the Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>24</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<td>4</td>
<td>5</td>
<td>6</td>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>31</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>
32. During the **past 4 weeks**, how much of the time has your **physical health or emotional problems** interfered with your social activities (like visiting with friends, relatives, etc.)?

(Circle One Number)

- All of the time 1
- Most of the time 2
- Some of the time 3
- A little of the time 4
- None of the time 5

How TRUE or FALSE is each of the following statements for you.

(Circle One Number on Each Line)

<table>
<thead>
<tr>
<th></th>
<th>Definitely True</th>
<th>Mostly True</th>
<th>Don’t Know</th>
<th>Mostly False</th>
<th>Definitely False</th>
</tr>
</thead>
<tbody>
<tr>
<td>33. I seem to get sick a little easier than other people</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>34. I am as healthy as anybody I know</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>35. I expect my health to get worse</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>36. My health is excellent</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
APPENDIX 16

DASS – 21 Questionnaire

Please read each statement and circle a number 0, 1, 2 or 3, which indicates how much the statement applied to you OVER THE PAST WEEK. There is no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0  Did not apply to me at all
1  Applied to me to some degree, or some of the time
2  Applied to me to a considerable degree, or a good part of time
3  Applied to me very much, or most of the time

<table>
<thead>
<tr>
<th>Statement</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I found it hard to wind down</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. I was aware of dryness of my mouth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. I couldn't seem to experience any positive feeling at all</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. I experienced breathing difficulty (e.g., excessively rapid breathing, or breathlessness in the absence of physical exertion)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. I found it difficult to work up the initiative to do things</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. I tended to over-react to situations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. I experienced trembling (eg, in the hands)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. I felt that I was using a lot of nervous energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. I was worried about situations in which I might panic and make a fool of myself</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. I felt that I had nothing to look forward to</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. I found myself getting agitated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. I found it difficult to relax</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. I felt down-hearted and blue</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. I was intolerant of anything that kept me from getting on with what I was doing</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Description</td>
<td>0</td>
<td>1</td>
<td>2</td>
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<tr>
<td>---</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>15</td>
<td>I felt I was close to panic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>I was unable to become enthusiastic about anything</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>I felt I wasn't worth much as a person</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>I felt that I was rather touchy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>I was aware of the action of my heart in the absence of physical exertion (e.g., sense of heart rate increase, heart missing a beat)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>I felt scared without any good reason</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>I felt that life was meaningless</td>
<td></td>
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**CODE NUMBER:**

**DATE:**
APPENDIX 17
Rand SF - 36 & DASS - 21 Scores Summary Form

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<th>ITEM NUMBERS:</th>
<th>NUMBER OF ITEMS:</th>
<th>TOTAL ITEM SCORE:</th>
<th>ITEM AVERAGE SCORE:</th>
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<td>ROLE LIMITATIONS DUE TO PHYSICAL HEALTH</td>
<td>13; 14; 15; 16</td>
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<td>ROLE LIMITATIONS DUE TO EMOTIONAL PROBLEMS</td>
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<tr>
<td>ENERGY / FATIGUE</td>
<td>23; 27; 29; 31</td>
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<td>EMOTIONAL WELL BEING</td>
<td>24; 25; 26; 28; 30</td>
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<td>SOCIAL FUNCTIONING</td>
<td>20; 32</td>
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<td>PAIN</td>
<td>21; 22</td>
<td>2</td>
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<td>GENERAL HEALTH</td>
<td>1; 33; 34; 35; 36</td>
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<th>NUMBER OF ITEMS:</th>
<th>TOTAL ITEM SCORE:</th>
<th>ITEM CONVERSION SCORE (X 2):</th>
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<td>DEPRESSION</td>
<td>3; 5; 10; 13; 16; 17; 21</td>
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<tr>
<td>ANXIETY</td>
<td>2; 4; 7; 9; 15; 19; 20;</td>
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<tr>
<td>STRESS</td>
<td>1; 6; 8; 11; 12; 14; 18;</td>
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CODE NUMBER:       DATE:
APPENDIX 18
Order of Questionnaires Summary Form

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<tr>
<td>QUESTIONNARIES:</td>
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<td>1. VAS (PAIN)</td>
</tr>
<tr>
<td>2. VAS (STRESS)</td>
</tr>
<tr>
<td>3. NDI</td>
</tr>
<tr>
<td>4. SF - 36</td>
</tr>
<tr>
<td>5. DASS - 21</td>
</tr>
<tr>
<td>SUBJECT:</td>
</tr>
<tr>
<td>----------</td>
</tr>
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</table>
# APPENDIX 19

**Participant Physical Measures & Mechanical Pain Threshold Tests Data Form**

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<tr>
<th>PARTICIPANT NAME:</th>
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</tr>
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<tbody>
<tr>
<td>PHYSICAL MEASURES:</td>
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</tr>
<tr>
<td>HEIGHT (CMS)</td>
<td></td>
</tr>
<tr>
<td>WEIGHT (KGS)</td>
<td>- 0.04</td>
</tr>
<tr>
<td>BMI (KG/M2)</td>
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</tr>
<tr>
<td>FOOT SIZE (US)</td>
<td>LEFT FOOT</td>
</tr>
<tr>
<td>FOOT WIDTH (US)</td>
<td>LEFT FOOT</td>
</tr>
<tr>
<td>LEG DOMINANCE TEST</td>
<td>RIGHT FOOT</td>
</tr>
<tr>
<td>MECHANICAL SENSORY THRESHOLD MEASURES:</td>
<td></td>
</tr>
<tr>
<td>PRESSURE ALGOMETER TEST:</td>
<td></td>
</tr>
<tr>
<td>A1. MOST SYMPTOMATIC NECK SITE</td>
<td>SITE:</td>
</tr>
<tr>
<td>OR</td>
<td></td>
</tr>
<tr>
<td>A2. ARTICULAR PILLAR C5 / C6</td>
<td>RESULT: (kg)</td>
</tr>
<tr>
<td></td>
<td>A. - 0.30</td>
</tr>
<tr>
<td></td>
<td>B. - 0.30</td>
</tr>
<tr>
<td></td>
<td>C. - 0.30</td>
</tr>
<tr>
<td>MEAN SCORE:</td>
<td></td>
</tr>
<tr>
<td>B. ASYMPOTOMATIC REMOTE SITE – TIBIALIS ANTERIOR MUSCLE BELLY</td>
<td>RESULT: (kg)</td>
</tr>
<tr>
<td></td>
<td>A. - 0.30</td>
</tr>
<tr>
<td></td>
<td>B. - 0.30</td>
</tr>
<tr>
<td></td>
<td>C. - 0.30</td>
</tr>
<tr>
<td>CODE NUMBER:</td>
<td>DATE: 169</td>
</tr>
<tr>
<td>MEAN SCORE:</td>
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</tr>
</tbody>
</table>
APPENDIX 20

Masscal Mass Calibration Report

Client: UNIVERSITY OF CANBERRA
UNIVERSITY DRIVE
BRUCE

Site Address: Unit 11, 21-23 Daniel Street, Wetherill Park NSW 2164

Report No: 64919 130260 14668

Calibration Date: 3/12/2010

Mass Details:
Manufacturer: Masscal/Avery
Serial No: Various
Model: N/A
Client Plant No: N/A
Location: Workshop


Initial Comments: Good Condition

PCS Reference: ZUC147

Reference Equipment: The calibration was performed using equipment traceable to National Standards of measurement.
Using Standard Reference Mass Set: 1251
The temperature during calibration was 20°C

Value of Masses: The measured values with their specified uncertainties given on the following
page of this certificate have been tested on the basis of weighings
made in air against standards of known mass and density.
The measured values represent the mass of an object of density 8000 kg/m³,
which in air of density 1.2 kg/m³ would balance the tested mass standards.
The uncertainties given in this certificate have been estimated using the following
guide as a reference:
Assessment of Uncertainties of Measurement for calibration & testing laboratories - RR Cook
Supplementary Example 1 - Calculation of the uncertainty of a mass calibration. SI7 Revl Sept/92

Uncertainty Information: Confidence Level 95% with a k Factor of 2

Signed: ______________________________
K. Stavros
Approved Signatory

Issue Date: __________________________

Page 1 of 2

This Laboratory is accredited by the NATIONAL ASSOCIATION OF TESTING AUTHORITIES, AUSTRALIA. The tests/measurements have been performed in accordance with the code of accreditation. This report may not be copied EXCEPT IN FULL.
APPENDIX 21

Kistler Force Plate 2 Weight Calibration Results Form

Date: 9th March 2012

<table>
<thead>
<tr>
<th>MASSCAL WEIGHT (KGS)</th>
<th>FORCE PLATE READING ONE</th>
<th>FORCE PLATE READING TWO</th>
<th>FORCE PLATE READING THREE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10.04</td>
<td>10.04</td>
<td>10.04</td>
<td>10.04</td>
<td>0.00</td>
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<tr>
<td>20</td>
<td>20.04</td>
<td>20.04</td>
<td>20.03</td>
<td>20.03666667</td>
<td>0.0057735</td>
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<td>30.03</td>
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<td>30.03666667</td>
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</table>
# APPENDIX 22

## Kistler Force Plate 2 Calibration Certificate

<table>
<thead>
<tr>
<th>Typ</th>
<th>Type</th>
<th>Serial No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serien-Nr</td>
<td>Type</td>
<td>Serial No</td>
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<tr>
<td>Mehrkomponenten-Aerospartform</td>
<td>Kalibrierte Raster 3</td>
<td>Calibrated Range 3</td>
</tr>
<tr>
<td></td>
<td>Kalibrierte Raster 1</td>
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<tr>
<td></td>
<td>9286AA</td>
<td>1092385</td>
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### Measurements

<table>
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<th>Measurand</th>
<th>Measurement</th>
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<tr>
<td>Fx</td>
<td>1.00 x 10^-4</td>
</tr>
<tr>
<td>Fy</td>
<td>1.00 x 10^-4</td>
</tr>
<tr>
<td>Fz</td>
<td>1.00 x 10^-4</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Umgangstemperatur</th>
<th>Relative Feuchtigkeit</th>
<th>Calibrated by</th>
<th>Datum</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>%</td>
<td>F. Heymann</td>
<td>21.03.01</td>
</tr>
</tbody>
</table>

We confirm that the device identified above was tested by the prescribed procedure. All measuring devices are traceable to national standards, the reference standards through the SCS (Swiss Calibration Service) Calibration Laboratory No. 049, operated by Kistler and accredited per EN 45001.

**Reference Equipment**

- Sensor: (Working Standards) - Kistler 3567A/8B
- Calibrator: Kistler 5230A/10284
- Voltage Calibrator: Kistler 518

**Serial No.**

- 128412/107002/470351
- 543233
- 313466

---

**Notes:**

- DO NOT LOSE
- PLATE 2 WILL NOT WORK WITHOUT THIS INFO
APPENDIX 23

Equipment List Summary Form

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
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<tr>
<td>INITIAL RECRUITMENT FORM X250</td>
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<tr>
<td>APPOINTMENT FORM X55</td>
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</tr>
<tr>
<td>RESEARCH PROJECT PARTICIPANT INFORMATION FORM X55</td>
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</tr>
<tr>
<td>PERSONAL INFORMATION FORM X55</td>
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<tr>
<td>UC INFORMED CONSENT FORM X55</td>
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<td>UC INDEPENDENT COMPLAINTS CONTACT FORM X55</td>
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<td>GROUP ALLOCATION FORM X2</td>
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</tr>
<tr>
<td>“THANK YOU for PARTICIPATING” LETTER FORM X55</td>
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<tr>
<td>DEMOGRAPHIC &amp; HISTORY DATA FORM X55</td>
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<td>BODY CHART FORM X55</td>
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<tr>
<td>VAS PAIN QUESTIONNAIRES (HUSKISSON, 1974) X55</td>
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<tr>
<td>VAS STRESS QUESTIONNAIRES (HUSKISSON, 1974) X55</td>
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<td>RAND SF – 36 QUESTIONNAIRES (WARE &amp; SHERBOURNE, 1992) X55</td>
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<td>DASS – 21 QUESTIONNAIRES (LOVIBOND &amp; LOVIBOND, 1995) X55</td>
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<td>DASS – 21 SCORING FORM X1</td>
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<td>ORDER OF BALANCE TESTS SUMMARY FORM X55</td>
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<tr>
<td>PHYSICAL MEASURES &amp; MECHANICAL PAIN THRESHOLD TEST DATA FORM X55</td>
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<td>FFT DATA FORM X55</td>
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<tr>
<td>RESEARCH PROJECT TEST PROTOCOL FORM X55</td>
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<td>MASSCAL WEIGHTS – 10 &amp; 20 KGS</td>
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<td>TAPE MEASURE + WALL ATTACHMENT</td>
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<td>CALCULATOR</td>
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<td>HAND-HELD DIAL PRESSURE ALGOMETER DEVICE</td>
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<td>SMART PHONES (iPOD TOUCH) X2</td>
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<td>SPIBELT LYCRA SLEEVES X2</td>
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<td>2. KISTLER BIOWARE VERSION 5.1.1.0X</td>
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<td>3. SIGVIEW 32 VERSION 2.4.0</td>
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APPENDIX 24

Pressure Algometer (Baseline Force Push/Pull Force Gauge)
Calibration Results Form

Date: 9\textsuperscript{th} February 2012

<table>
<thead>
<tr>
<th>PUSH GAUGE READING (KGS)</th>
<th>QUATTRO JUMP READING ONE (KGS)</th>
<th>QUATTRO JUMP READING TWO (KGS)</th>
<th>QUATTRO JUMP READING THREE (KGS)</th>
<th>MEAN</th>
<th>STANDARD DEVIATION (SD)</th>
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Kistler Quattro Jump
Model: 9290AD
Serial Number: 1235140
Calibration of Kistler Quattro Jump Results Form

Date: 9\textsuperscript{th} February 2012

<table>
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<tr>
<th>CALIBRATION WEIGHT (KGS)</th>
<th>QUATTRO JUMP READING ONE (KGS)</th>
<th>QUATTRO JUMP READING TWO (KGS)</th>
<th>QUATTRO JUMP READING THREE (KGS)</th>
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APPENDIX 25
Order of Balance Tests Summary Form

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<th>BALANCE TESTS NUMBERING KEY:</th>
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<tr>
<td><strong>STATIC BALANCE TEST MEASURES:</strong></td>
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<td>1. SINGLE LEGGED STANCE (SLS)</td>
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<td>2. “COMFORTABLE” LEG STANCE (CS)</td>
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<tr>
<td>3. “NARROW” LEG STANCE (NS)</td>
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<tr>
<td><strong>DYNAMIC BALANCE TEST MEASURES:</strong></td>
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<td>4. “NORMAL” WALKING (NW)</td>
</tr>
<tr>
<td>5. TANDEM or “FIELD SOBRIETY” WALKING (TW)</td>
</tr>
<tr>
<td>SUBJECT</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>48</td>
</tr>
<tr>
<td>49</td>
</tr>
<tr>
<td>50</td>
</tr>
</tbody>
</table>
APPENDIX 26

Balance Tests - Leg Dominance Form

<table>
<thead>
<tr>
<th>BALANCE TEST AND ORDER</th>
<th>FIRST LEG ENGAGED IN TESTING (DOMINANT)</th>
<th>TIME FIRST LEG ENGAGED ON FORCE PLATE (SECONDS)</th>
<th>FIRST LEG ENGAGED ON FORCE PLATE</th>
<th>SECOND LEG ENGAGED ON FORCE PLATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Legged Stance (SLS) 1</td>
<td>L R</td>
<td>L R</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Comfortable Stance (CS) 2</td>
<td>L R</td>
<td>L R</td>
<td>L R</td>
<td></td>
</tr>
<tr>
<td>Narrow Stance (NS) 3</td>
<td>L R</td>
<td>L R</td>
<td>L R</td>
<td></td>
</tr>
<tr>
<td>Normal Walking (NW) 4</td>
<td>L R</td>
<td>L R</td>
<td>L R</td>
<td></td>
</tr>
<tr>
<td>Tandem Walking (TW) 5</td>
<td>L R</td>
<td>L R</td>
<td>L R</td>
<td></td>
</tr>
</tbody>
</table>

CODE NUMBER: DATE:
## APPENDIX 27

### Test Procedure Form

<table>
<thead>
<tr>
<th>PARTICIPANT NAME:</th>
<th>PARTICIPANT CODE NUMBER:</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE:</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEST PROCEDURE:</th>
<th>COMPLETED:</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROVIDE BRIEF EXPLANATION OF RESEARCH PROJECT</td>
<td></td>
</tr>
<tr>
<td>DISTRIBUTE RESEARCH PROJECT INFORMATION FORM</td>
<td></td>
</tr>
<tr>
<td>ANSWER QUESTION (S) PRIOR TO TEST COMMENCEMENT (PART 1)</td>
<td></td>
</tr>
<tr>
<td>DISTRIBUTE PARTICIPANT INFORMED CONSENT FORM</td>
<td></td>
</tr>
<tr>
<td>COLLECT SIGNED PARTICIPANT INFORMED CONSENT FORM</td>
<td></td>
</tr>
<tr>
<td>DISTRIBUTE PARTICIPANT PERSONAL INFORMATION FORM</td>
<td></td>
</tr>
<tr>
<td>COLLECT COMPLETED PARTICIPANT PERSONAL INFORMATION FORM</td>
<td></td>
</tr>
<tr>
<td>DISTRIBUTE PARTICIPANT DEMOGRAPHIC &amp; HISTORY DATA FORM, BODY CHART &amp; THE FOLLOWING QUESTIONNAIRES:</td>
<td></td>
</tr>
<tr>
<td>1. VAS PAIN</td>
<td></td>
</tr>
<tr>
<td>2. VAS STRESS</td>
<td></td>
</tr>
<tr>
<td>3. NDI</td>
<td></td>
</tr>
<tr>
<td>4. SF – 36</td>
<td></td>
</tr>
<tr>
<td>5. DASS – 21</td>
<td></td>
</tr>
<tr>
<td>COLLECT COMPLETED PARTICIPANT DEMOGRAPHIC &amp; HISTORY DATA FORM, BODY CHART &amp; QUESTIONNAIRES (X5)</td>
<td></td>
</tr>
<tr>
<td>CONFIRM PARTICIPANT ELIGIBILITY –</td>
<td></td>
</tr>
<tr>
<td>1. &gt; 18 YEARS</td>
<td></td>
</tr>
<tr>
<td>2. <strong>FOR CONTROL PARTICIPANTS</strong> – NO CURRENT NECK / SHOULDER PAIN OR ACHE, HEADACHES OR DIZZINESS OR RELATED HISTORY</td>
<td></td>
</tr>
<tr>
<td>3. <strong>FOR CHRONIC NECK PAIN PARTICIPANTS</strong> –</td>
<td></td>
</tr>
<tr>
<td>1. CURRENT &amp; CONFIRMED ON A BODY CHART</td>
<td></td>
</tr>
<tr>
<td>2. LOCATION - NECK</td>
<td></td>
</tr>
<tr>
<td>3. 3 MONTHS DURATION</td>
<td></td>
</tr>
<tr>
<td>4. VAS PAIN SCORE 1</td>
<td></td>
</tr>
<tr>
<td>5. NDI SCORE 10</td>
<td></td>
</tr>
<tr>
<td>4. <strong>EXCLUSION CRITERIA</strong> –</td>
<td></td>
</tr>
<tr>
<td>1. HISTORY OF SYSTEMIC RHEUMATIC OR NEUROLOGICAL DISEASE (S)</td>
<td></td>
</tr>
<tr>
<td>2. UNEXPLAINED LOSS OF CONSCIOUSNESS IN THE PAST YEAR</td>
<td></td>
</tr>
<tr>
<td>3. VESTIBULAR PATHOLOGY</td>
<td></td>
</tr>
<tr>
<td>4. MAJOR VISUAL OR HEARING DEFICITS</td>
<td></td>
</tr>
<tr>
<td>5. DIABETES (TYPE 1 OR 2)</td>
<td></td>
</tr>
<tr>
<td>6. UNCONTROLLED ABNORMAL BLOOD PRESSURE</td>
<td></td>
</tr>
<tr>
<td>7. SPINAL FRACTURE AND / OR DISLOCATION</td>
<td></td>
</tr>
<tr>
<td>8. PRIOR SPINAL SURGERY</td>
<td></td>
</tr>
<tr>
<td>9. MAJOR JOINT OR NERVE INJURY, ESPECIALLY OF THE LOWER LIMBS</td>
<td></td>
</tr>
<tr>
<td>10. DIAGNOSED PSYCHIATRIC DISORDER</td>
<td></td>
</tr>
</tbody>
</table>

ANSWER QUESTION (S) PRIOR TO TEST COMMENCEMENT (PART 2)
**COMPLETE PHYSICAL MEASUREMENTS & MECHANICAL SENSORY THRESHOLD TESTS DATA FORM**

**ENSURE PARTICIPANTS ARE BAREFOOTED.** Include the following measures:

1. **HEIGHT (CMS)**
2. **WEIGHT (KGS)**
3. **BMI (KGS / M2)**
4. **FOOT SIZE (US):**
   1. LEFT FOOT
   2. RIGHT FOOT
5. **FOOT WIDTH (US):**
   1. LEFT FOOT
   2. RIGHT FOOT
6. **FOOT DOMINANCE**
7. **PRESSURE ALGOMETER:**
   1. MOST SYMPTOMATIC NECK SITE (IPSILATERAL) (X3)
   2. ASYMPTOMATIC REMOTE SITE – TIBIALIS ANTERIOR MUSCLE BELLY (IPSILATERAL) (X3)

**CALCULATE MEAN SCORES**

**PERFORMED BALANCE TESTS. ENSURE PARTICIPANTS ARE BAREFOOTED.**

**STATIC BALANCE TEST MEASURES – HOLDING FOR 30 SECONDS:**

1. SINGLE LEGGED STANCE (SLS)
2. “COMFORTABLE” LEG STANCE (CS)
3. “NARROW” LEG STANCE (NS)

**DYNAMIC BALANCE TEST MEASURES – MEASURING THE MIDDLE STRIDE:**

4. “NORMAL” WALKING (NW)
5. TANDEM OR “FIELD SOBRIETY” WALKING (TW)

**COMPLETE BALANCE TESTS & LEG DOMINANCE FORM**

**DISTRIBUTE INDEPENDENT COMPLAINTS CONTACT FORM**

**ANSWER PARTICIPANT QUESTION (S) AT COMPLETION OF TESTING**

**CHECK ALL FORMS & QUESTIONNAIRES ARE COMPLETED & TABLED**

**CHECK, AUTHENTICATE AND PRINT COMPUTER GENERATED TEST RESULTS**

“BACK UP” COMPUTER GENERATED TEST RESULTS

**DISTRIBUTE PARTICIPANT THANK YOU FOR PARTICIPATION LETTER**

---

| CODE NUMBER: | DATE: |
APPENDIX 28

Example of Dynamic Balance Tests Graphs

Normal Walking Dynamic Balance Test

Tandem Walking Dynamic Balance Test
### APPENDIX 29

#### FFT Data Form

<table>
<thead>
<tr>
<th>PARTICIPANT NUMBER</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EQUIPMENT</td>
<td></td>
</tr>
<tr>
<td>BALANCE TEST</td>
<td></td>
</tr>
<tr>
<td>AXIS</td>
<td></td>
</tr>
<tr>
<td>TEST DURATION (SEC)</td>
<td></td>
</tr>
<tr>
<td>STANDARD DEVIATION (SD)</td>
<td></td>
</tr>
<tr>
<td>ROOT MEAN SQUARE (RMS)</td>
<td></td>
</tr>
<tr>
<td>FFT WEIGHTED MEAN - MEAN FREQUENCY (HZ)</td>
<td></td>
</tr>
<tr>
<td>FFT MAXIMUM POSITION WITH MARKER (HZ)</td>
<td></td>
</tr>
</tbody>
</table>

**CODE NUMBER:**

**DATE:**
APPENDIX 30

Independent samples test of Levene’s Test for Equality of Variances (F) results for all scale measures.

<table>
<thead>
<tr>
<th>LEVENE’S TEST for EQUALITY of VARIANCES (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Variance Assumed (Sig &gt; 0.05)</td>
</tr>
<tr>
<td>Number of Prescribed Medications</td>
</tr>
<tr>
<td>VAS (Stress)</td>
</tr>
<tr>
<td>NDI</td>
</tr>
<tr>
<td>SF – 36:</td>
</tr>
<tr>
<td>b. E / F</td>
</tr>
<tr>
<td>c. SF</td>
</tr>
<tr>
<td>d. P</td>
</tr>
<tr>
<td>DASS – 21</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>BMI (kg/m2)</td>
</tr>
<tr>
<td>Foot size (US) – Left &amp; Right</td>
</tr>
<tr>
<td>Foot width (US) – Right</td>
</tr>
<tr>
<td>MPTT - Cervical Spine Site</td>
</tr>
<tr>
<td>MPTT - Asymptomatic Remote Site</td>
</tr>
</tbody>
</table>

VAS = Visual Analogue Scale; NDI = Neck Disability Index; SF-36 = The Short Form Health Survey; PH = Physical Functioning; RL – PH = Role Limitation – Physical Health; RL – EB = Role Limitation – Emotional Problems; E / F = Energy / Fatigue; EW – B = Emotional Well Being; SF= Social Functioning; P = Pain; GH = General Health; DASS – 21 = Depression (D) Anxiety (A) Stress (S) Scales; BMI = Body Mass Index; MPTT = Mechanical Pain Threshold Test.
APPENDIX 31

Demographic and history data nominal measures for all participants, the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>DEMOGRAPHIC &amp; HISTORY MEASURES</th>
<th>ALL PARTICIPANTS (n=50)</th>
<th>CONTROL (n=25)</th>
<th>CHRONIC NECK PAIN (n=25)</th>
<th>p - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Referral Basis:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Practitioner referred</td>
<td>17</td>
<td>6</td>
<td>11</td>
<td>0.136</td>
</tr>
<tr>
<td>b. Self-referred</td>
<td>33</td>
<td>19</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Gender:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Males</td>
<td>20</td>
<td>16</td>
<td>4</td>
<td>0.001*</td>
</tr>
<tr>
<td>b. Females</td>
<td>30</td>
<td>9</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Occupation:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Student</td>
<td>12</td>
<td>11</td>
<td>1</td>
<td>0.008* (FETR)</td>
</tr>
<tr>
<td>b. Sedentary Worker</td>
<td>26</td>
<td>9</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>c. Manual Worker</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>d. Retired</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Origin of Symptoms:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Trauma</td>
<td>NA</td>
<td>NA</td>
<td>10</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>b. Insidious</td>
<td>NA</td>
<td>NA</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>(Non - Traumatic)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Asymp. Sig. (2-sided) * p < 0.05; n = number; FETR = Fisher’s Exact Test Result; NA = Not answered.
APPENDIX 32

Demographic and history data scale measures for all participants.

<table>
<thead>
<tr>
<th>DEMOGRAPHIC &amp; HISTORY MEASURES</th>
<th>ALL PARTICIPANTS (n=50)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD &amp; Range)</td>
</tr>
<tr>
<td>Age (Years)</td>
<td>46.06 (15.41; 20.00 – 70.00)</td>
</tr>
<tr>
<td>Number of Prescribed Medications</td>
<td>0.60 (1.16; 0.00 – 4.00)</td>
</tr>
<tr>
<td>Duration of Symptoms (Years)</td>
<td>NA</td>
</tr>
</tbody>
</table>

$n = \text{number}; \ SD = \text{Standard Deviation}; \ NA = \text{Not answered.}$
APPENDIX 33

Demographic and history data scale measures for the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>DEMOGRAPHIC &amp; HISTORY MEASURES</th>
<th>CONTROL ((n=25)) Mean (SD &amp; Range)</th>
<th>CHRONIC NECK PAIN ((n=25)) Mean (SD &amp; Range)</th>
<th>(p) - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>44.16 (17.69; 20.00 – 70.00)</td>
<td>47.96 (12.82; 21.00 – 69.00)</td>
<td>0.389</td>
</tr>
<tr>
<td>Number of Prescribed Medications</td>
<td>0.48 (1.12; 0.00 – 4.00)</td>
<td>0.72 (1.21; 0.00 – 4.00)</td>
<td>0.470</td>
</tr>
<tr>
<td>Duration of symptoms (Years)</td>
<td>NA</td>
<td>14.08 (12.44; 0.42 – 40.00)</td>
<td>&lt; 0.001*</td>
</tr>
</tbody>
</table>

Asymp. Sig. (2-sided) * \(p < 0.05\); \(n\) = number; SD = Standard Deviation; NA = Not answered.
APPENDIX 34

Self-rated questionnaire measures for the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>SELF- RATED QUESTIONNAIRE MEASURES</th>
<th>CONTROL (n=25) Mean (SD)</th>
<th>CHRONIC NECK PAIN (n=25) Mean (SD)</th>
<th>p – Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS (Pain)</td>
<td>0.39 (0.80)</td>
<td>2.56 (1.33)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>VAS (Stress)</td>
<td>1.63 (2.36)</td>
<td>2.11 (1.82)</td>
<td>0.427</td>
</tr>
<tr>
<td>NDI</td>
<td>2.84 (3.40)</td>
<td>11.40 (5.35)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>SF – 36:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. PF</td>
<td>94.20 (7.46)</td>
<td>79.80 (21.91)</td>
<td>0.004*</td>
</tr>
<tr>
<td>b. RL – PH</td>
<td>92.00 (24.71)</td>
<td>63.00 (41.53)</td>
<td>0.005*</td>
</tr>
<tr>
<td>c. RL – EP</td>
<td>90.67 (24.57)</td>
<td>78.67 (39.53)</td>
<td>0.205</td>
</tr>
<tr>
<td>d. E/F</td>
<td>65.20 (16.68)</td>
<td>54.00 (12.58)</td>
<td>0.010*</td>
</tr>
<tr>
<td>e. EW – B</td>
<td>82.56 (14.04)</td>
<td>79.52 (8.43)</td>
<td>0.359</td>
</tr>
<tr>
<td>f. SF</td>
<td>89.50 (17.18)</td>
<td>82.50 (18.75)</td>
<td>0.175</td>
</tr>
<tr>
<td>g. P</td>
<td>86.80 (12.94)</td>
<td>65.70 (18.84)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>h. GH</td>
<td>78.20 (13.14)</td>
<td>64.20 (19.98)</td>
<td>0.006*</td>
</tr>
<tr>
<td>DASS – 21:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. D</td>
<td>2.72 (4.31)</td>
<td>2.56 (2.55)</td>
<td>0.874</td>
</tr>
<tr>
<td>b. A</td>
<td>3.12 (4.04)</td>
<td>3.44 (3.44)</td>
<td>0.764</td>
</tr>
<tr>
<td>c. S</td>
<td>8.08 (7.34)</td>
<td>9.60 (6.53)</td>
<td>0.443</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) * p < 0.05; n = number; SD = Standard Deviation; VAS = Visual Analogue Scale; NDI = Neck Disability Index; SF-36 = The Short Form Health Survey; DASS – 21 = Depression (D) Anxiety (A) Stress (S) Scales.
APPENDIX 35

Physical nominal measure for all participants, the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>PHYSICAL MEASURES</th>
<th>ALL PARTICIPANTS (n=50)</th>
<th>CONTROL (n=25)</th>
<th>CHRONIC NECK PAIN (n=25)</th>
<th>p - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg Dominance:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Left</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1.000</td>
</tr>
<tr>
<td>b. Right</td>
<td>49</td>
<td>25</td>
<td>24</td>
<td>(FETR)</td>
</tr>
</tbody>
</table>

\( n = \text{number}; \text{FETR} = \text{Fisher’s Exact Test Result.} \)
APPENDIX 36

Physical scale measures for all participants, the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>PHYSICAL MEASURES</th>
<th>ALL PARTICIPANTS ( (n=50) ) Mean (SD)</th>
<th>CONTROL ( (n=25) ) Mean (SD)</th>
<th>CHRONIC NECK PAIN ( (n=25) ) Mean (SD)</th>
<th>( p ) - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>170.79 (8.57)</td>
<td>172.89 (8.85)</td>
<td>168.68 (7.89)</td>
<td>0.083</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.78 (11.99)</td>
<td>71.22 (13.36)</td>
<td>70.34 (10.70)</td>
<td>0.796</td>
</tr>
<tr>
<td>BMI (kg/m2)</td>
<td>24.29 (4.19)</td>
<td>23.71 (3.50)</td>
<td>24.88 (4.78)</td>
<td>0.329</td>
</tr>
<tr>
<td>Foot size (US)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Left</td>
<td>8.53 (1.72)</td>
<td>8.89 (1.73)</td>
<td>8.16 (1.67)</td>
<td>0.135</td>
</tr>
<tr>
<td>b. Right</td>
<td>8.64 (1.68)</td>
<td>9.01 (1.64)</td>
<td>8.26 (1.66)</td>
<td>0.115</td>
</tr>
<tr>
<td>Foot width (US)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Left</td>
<td>3.46 (1.30)</td>
<td>3.98 (1.45)</td>
<td>2.94 (0.87)</td>
<td>0.004*</td>
</tr>
<tr>
<td>b. Right</td>
<td>3.50 (1.13)</td>
<td>3.82 (1.16)</td>
<td>3.18 (1.02)</td>
<td>0.044*</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) * \( p < 0.05 \); \( n \) = number; SD = Standard Deviation; BMI = Body Mass Index; US = United States.
APPENDIX 37

Mechanical pain threshold measures for the control and chronic neck pain groups.

| MPTT MEASURES                | CONTROL  
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(n=25) Mean (SD) (kPa)</td>
<td>CHRONIC NECK PAIN (n=25) Mean (SD) (kPa)</td>
</tr>
<tr>
<td>Cervical Spine Site</td>
<td>C5 / C6 AP site</td>
</tr>
<tr>
<td>2.87 (0.88)</td>
<td>2.04 (0.90)</td>
</tr>
<tr>
<td>Asymptomatic Remote Site</td>
<td>6.77 (1.99)</td>
</tr>
<tr>
<td>(TA Muscle Belly)</td>
<td></td>
</tr>
</tbody>
</table>

Sig. (2-tailed) * p < 0.05; n = number; SD = Standard Deviation; C = Cervical; AP = Articular pillar; MPTT = Mechanical Pain Threshold Test; kPa = Kilopascals.
APPENDIX 38

Balance tests - FFT Mean frequency measures in the AP direction for the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>BALANCE MEASURES</th>
<th>CONTROL (n=25) Mean (SD)</th>
<th>CHRONIC NECK PAIN (n=25) Mean (SD)</th>
<th>p - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP SLS Y</td>
<td>3.72 (0.64)</td>
<td>3.68 (0.42)</td>
<td>.796</td>
</tr>
<tr>
<td>FP CS Y</td>
<td>3.69 (0.59)</td>
<td>3.46 (0.52)</td>
<td>.146</td>
</tr>
<tr>
<td>FP NS Y</td>
<td>3.43 (0.52)</td>
<td>3.19 (0.47)</td>
<td>.088</td>
</tr>
<tr>
<td>FP NW Y</td>
<td>3.51 (1.33)</td>
<td>2.93 (0.75)</td>
<td>.063</td>
</tr>
<tr>
<td>FP TW Y</td>
<td>3.33 (0.68)</td>
<td>3.35 (0.77)</td>
<td>.949</td>
</tr>
<tr>
<td>SP SLS Z</td>
<td>5.07 (0.75)</td>
<td>4.95 (0.87)</td>
<td>.593</td>
</tr>
<tr>
<td>SP CS Z</td>
<td>4.62 (0.93)</td>
<td>4.33 (0.84)</td>
<td>.245</td>
</tr>
<tr>
<td>SP NS Z</td>
<td>4.29 (0.82)</td>
<td>4.05 (0.64)</td>
<td>.262</td>
</tr>
<tr>
<td>SP NW Z</td>
<td>4.14 (1.01)</td>
<td>4.43 (0.91)</td>
<td>.934</td>
</tr>
<tr>
<td>SP TW Z</td>
<td>4.14 (0.83)</td>
<td>4.01 (0.77)</td>
<td>.570</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) * p < 0.05; n = number; SD = Standard Deviation; AP = Anterior-posterior; FFT = Fast Fourier Transform; FP = Force Plate; SP = Smart Phone; AP = Anterior-posterior axis; SLS = Single Leg Stance; CS = Comfortable Stance; NS = Narrow Stance; NW = Normal Walking; TW = Tandem Walking.
### APPENDIX 39

Balance tests - FFT Mean frequency measures in the ML direction for the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>BALANCE MEASURES</th>
<th>CONTROL (n=25) Mean (SD)</th>
<th>CHRONIC NECK PAIN (n=25) Mean (SD)</th>
<th>p - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP SLS X</td>
<td>4.07 (.62)</td>
<td>3.88 (.53)</td>
<td>.270</td>
</tr>
<tr>
<td>FP CS X</td>
<td>3.71 (.52)</td>
<td>3.58 (.70)</td>
<td>.447</td>
</tr>
<tr>
<td>FP NS X</td>
<td>3.19 (.46)</td>
<td>3.26 (.51)</td>
<td>.629</td>
</tr>
<tr>
<td>FP NW X</td>
<td>3.72 (.98)</td>
<td>4.06 (.92)</td>
<td>.214</td>
</tr>
<tr>
<td>FP TW X</td>
<td>4.41 (.77)</td>
<td>4.22 (.71)</td>
<td>.349</td>
</tr>
<tr>
<td>SP SLS Y</td>
<td>5.01 (.55)</td>
<td>4.65 (.57)</td>
<td>.029*</td>
</tr>
<tr>
<td>SP CS Y</td>
<td>4.70 (.56)</td>
<td>4.40 (.66)</td>
<td>.090</td>
</tr>
<tr>
<td>SP NS Y</td>
<td>4.47 (.62)</td>
<td>4.36 (.52)</td>
<td>.491</td>
</tr>
<tr>
<td>SP NW Y</td>
<td>4.55 (.67)</td>
<td>4.40 (1.06)</td>
<td>.545</td>
</tr>
<tr>
<td>SP TW Y</td>
<td>4.48 (.68)</td>
<td>4.34 (.55)</td>
<td>.449</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) * $p < 0.05$; $n$ = number; SD = Standard Deviation; ML = Medio-lateral; FFT = Fast Fourier Transform; FP = Force Plate; SP = Smart Phone; SLS = Single Leg Stance; CS = Comfortable Stance; NS = Narrow Stance; NW = Normal Walking; TW = Tandem Walking.
APPENDIX 40

Balance tests - FFT Mean frequency measures in the vertical direction for the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>BALANCE MEASURES</th>
<th>CONTROL (n=25) Mean (SD)</th>
<th>CHRONIC NECK PAIN (n=25) Mean (SD)</th>
<th>p - Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP SLS Z</td>
<td>4.90 (.43)</td>
<td>4.89 (.49)</td>
<td>.920</td>
</tr>
<tr>
<td>FP CS Z</td>
<td>5.73 (.46)</td>
<td>5.52 (.53)</td>
<td>.145</td>
</tr>
<tr>
<td>FP NS Z</td>
<td>5.42 (.60)</td>
<td>5.55 (.51)</td>
<td>.403</td>
</tr>
<tr>
<td>FP NW Z</td>
<td>2.84 (.98)</td>
<td>2.85 (.97)</td>
<td>.977</td>
</tr>
<tr>
<td>FP TW Z</td>
<td>4.29 (.52)</td>
<td>4.19 (.51)</td>
<td>.491</td>
</tr>
<tr>
<td>SP SLS X</td>
<td>6.49 (.63)</td>
<td>6.26 (.48)</td>
<td>.158</td>
</tr>
<tr>
<td>SP CS X</td>
<td>6.20 (.65)</td>
<td>5.89 (.50)</td>
<td>.064</td>
</tr>
<tr>
<td>SP NS X</td>
<td>6.09 (.62)</td>
<td>5.60 (.56)</td>
<td>.005*</td>
</tr>
<tr>
<td>SP NW X</td>
<td>5.14 (1.01)</td>
<td>4.95 (.71)</td>
<td>.443</td>
</tr>
<tr>
<td>SP TW X</td>
<td>5.50 (.95)</td>
<td>5.24 (.79)</td>
<td>.310</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) * p < 0.05; n = number; SD = Standard Deviation; FFT = Fast Fourier Transform; FP = Force Plate; SP = Smart Phone; SLS = Single Leg Stance; CS = Comfortable Stance; NS = Narrow Stance; NW = Normal Walking; TW = Tandem Walking.
APPENDIX 41

Number of significant Pearson’s \( r \) correlation coefficients between CFP and Smart Phone for the frequency-domain measures in AP, ML & vertical directions for all five balance tests.

<table>
<thead>
<tr>
<th>DIRECTIONS &amp; FREQUENCY- DOMAIN MEASURES</th>
<th>NUMBER OF SIGNIFICANT PEARSON’S ( r ) CORRELATION COEFFICIENTS (Maximum possible number is five)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ALL PARTICIPANTS (n=50)</td>
</tr>
<tr>
<td>AP:</td>
<td></td>
</tr>
<tr>
<td>a. SD</td>
<td>0</td>
</tr>
<tr>
<td>b. RMS</td>
<td>0</td>
</tr>
<tr>
<td>c. FFT MEAN FREQ</td>
<td>4</td>
</tr>
<tr>
<td>d. FFT MAX FREQ</td>
<td>2</td>
</tr>
<tr>
<td>ML:</td>
<td></td>
</tr>
<tr>
<td>a. SD</td>
<td>2</td>
</tr>
<tr>
<td>b. RMS</td>
<td>0</td>
</tr>
<tr>
<td>c. FFT MEAN FREQ</td>
<td>4</td>
</tr>
<tr>
<td>d. FFT MAX FREQ</td>
<td>1</td>
</tr>
<tr>
<td>Vertical:</td>
<td></td>
</tr>
<tr>
<td>a. SD</td>
<td>2</td>
</tr>
<tr>
<td>b. RMS</td>
<td>1</td>
</tr>
<tr>
<td>c. FFT MEAN FREQ</td>
<td>3</td>
</tr>
<tr>
<td>d. FFT MAX FREQ</td>
<td>1</td>
</tr>
</tbody>
</table>

AP = Anterior-posterior; ML = Medio-lateral; SD = Standard Deviation; RMS = Root Mean Square; FFT = Fast Fourier Transform; FREQ = Frequency
APPENDIX 42

Correlations ($r$) between CFP and Smart Phone balance tests - FFT Mean frequency measure in AP, ML & vertical directions for each balance test for all participants ($n = 50$).

<table>
<thead>
<tr>
<th>BALANCE TESTS</th>
<th>AP DIRECTION</th>
<th>ML DIRECTION</th>
<th>VERTICAL DIRECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS</td>
<td>.473**</td>
<td>.392**</td>
<td>.437**</td>
</tr>
<tr>
<td>CS</td>
<td>.527**</td>
<td>.460**</td>
<td>.105</td>
</tr>
<tr>
<td>NS</td>
<td>.458**</td>
<td>.437**</td>
<td>.045</td>
</tr>
<tr>
<td>NW</td>
<td>.206</td>
<td>.266</td>
<td>.282*</td>
</tr>
<tr>
<td>TW</td>
<td>.475**</td>
<td>.488**</td>
<td>.297*</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) ** $p < 0.01$; * $p < 0.05$; $n =$ number; $r =$ Pearson’s product-movement correlation coefficient; AP = Anterior-posterior axis; ML = Medio-lateral axis; FFT = Fast Fourier Transform; SLS = Single Leg Stance; CS = Comfortable Stance; NS = Narrow Stance; NW = Normal Walking; TW = Tandem Walking.
APPENDIX 43

Correlations ($r$) between CFP and Smart Phone balance tests - FFT Mean frequency measure in AP, ML & vertical directions for each balance test for the control group ($n = 25$).

<table>
<thead>
<tr>
<th>BALANCE TESTS</th>
<th>AP DIRECTION</th>
<th>ML DIRECTION</th>
<th>VERTICAL DIRECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS</td>
<td>.508**</td>
<td>.422*</td>
<td>.584**</td>
</tr>
<tr>
<td>CS</td>
<td>.532**</td>
<td>.479*</td>
<td>.181</td>
</tr>
<tr>
<td>NS</td>
<td>.534**</td>
<td>.419*</td>
<td>.050</td>
</tr>
<tr>
<td>NW</td>
<td>.205</td>
<td>.184</td>
<td>.366</td>
</tr>
<tr>
<td>TW</td>
<td>.561**</td>
<td>.524**</td>
<td>.407*</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) ** $p < 0.01$; * $p < 0.05$; $n =$ number; $r =$ Pearson’s product-movement correlation coefficient; AP = Anterior-posterior axis; ML = Medio-lateral axis; FFT = Fast Fourier Transform; SLS = Single Leg Stance; CS = Comfortable Stance; NS = Narrow Stance; NW = Normal Walking; TW = Tandem Walking.
APPENDIX 44

Correlations ($r$) between CFP and Smart Phone balance tests - FFT Mean frequency measure in AP, ML & vertical directions for each balance test for the chronic neck pain group ($n = 25$).

<table>
<thead>
<tr>
<th>BALANCE TESTS</th>
<th>AP DIRECTION</th>
<th>ML DIRECTION</th>
<th>VERTICAL DIRECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS</td>
<td>.468*</td>
<td>.304</td>
<td>.297</td>
</tr>
<tr>
<td>CS</td>
<td>.483*</td>
<td>.433*</td>
<td>.092</td>
</tr>
<tr>
<td>NS</td>
<td>.302</td>
<td>.486*</td>
<td>.071</td>
</tr>
<tr>
<td>NW</td>
<td>.257</td>
<td>.131</td>
<td>.177</td>
</tr>
<tr>
<td>TW</td>
<td>.405*</td>
<td>.331</td>
<td>.140</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) ** $p < 0.01$; * $p < 0.05$; $n =$ number; $r =$ Pearson’s product-movement correlation coefficient; AP = Anterior-posterior axis; ML = Medio-lateral axis; FFT = Fast Fourier Transform; SLS = Single Leg Stance; CS = Comfortable Stance; NS = Narrow Stance; NW = Normal Walking; TW = Tandem Walking.
APPENDIX 45

Number of significant Pearson’s $r$ correlation coefficients between CFP FFT Mean frequency and self-rating questionnaire measures in AP, ML & vertical directions for both the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>DIRECTIONS</th>
<th>CONTROL $(n=25)$</th>
<th>CHRONIC NECK PAIN $(n=25)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>ML</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Vertical</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

AP = Anterior-posterior; ML = Medio-lateral
APPENDIX 46

Number of significant Pearson’s $r$ correlation coefficients between Smart Phone FFT Mean frequency and self-rating questionnaire measures in AP, ML & vertical directions for both the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>DIRECTIONS</th>
<th>CONTROL $(n=25)$</th>
<th>CHRONIC NECK PAIN $(n=25)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>ML</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Vertical</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

AP = Anterior-posterior; ML = Medio-lateral
Number of significant Pearson’s $r$ correlation coefficients between CFP FFT Mean frequency and mechanical pain threshold testing measures in AP, ML & vertical directions for both the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>DIRECTIONS</th>
<th>CONTROL $(n=25)$</th>
<th>CHRONIC NECK PAIN $(n=25)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ML</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vertical</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

AP = Anterior-posterior; ML = Medio-lateral
APPENDIX 48

Number of significant Pearson’s $r$ correlation coefficients between Smart Phone FFT Mean frequency and mechanical pain threshold testing measures in AP, ML & vertical directions for both the control and chronic neck pain groups.

<table>
<thead>
<tr>
<th>DIRECTIONS</th>
<th>CONTROL (n=25)</th>
<th>CHRONIC NECK PAIN (n=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>ML</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Vertical</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

AP = Anterior-posterior; ML = Medio-lateral
APPENDIX 49

Correlations \((r)\) between self-rated questionnaire and mechanical pain threshold measures for the control group \((n = 25)\).

<table>
<thead>
<tr>
<th>SELF - RATED QUESTIONNAIRE MEASURES</th>
<th>MPTT MEASURES</th>
<th>Cervical Spine Site (C5 / C6 AP site)</th>
<th>Asymptomatic Remote Site (TA Muscle Belly)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS (Pain)</td>
<td></td>
<td>(r \cdot 0.123)</td>
<td>(r \cdot 0.080)</td>
</tr>
<tr>
<td>VAS (Stress)</td>
<td></td>
<td>(r \cdot 0.401^*)</td>
<td>(r \cdot 0.236)</td>
</tr>
<tr>
<td>NDI</td>
<td></td>
<td>(r \cdot 0.491^*)</td>
<td>(r \cdot 0.319)</td>
</tr>
<tr>
<td>SF – 36:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. PF</td>
<td></td>
<td>(r \cdot 0.304)</td>
<td>(r \cdot 0.205)</td>
</tr>
<tr>
<td>b. RL – PH</td>
<td></td>
<td>(r \cdot 0.142)</td>
<td>(r \cdot 0.112)</td>
</tr>
<tr>
<td>e. RL – EP</td>
<td></td>
<td>(r \cdot 0.193)</td>
<td>(r \cdot 0.147)</td>
</tr>
<tr>
<td>f. E / F</td>
<td></td>
<td>(r \cdot 0.271)</td>
<td>(r \cdot 0.057)</td>
</tr>
<tr>
<td>g. EW – B</td>
<td></td>
<td>(r \cdot 0.335)</td>
<td>(r \cdot 0.144)</td>
</tr>
<tr>
<td>h. SF</td>
<td></td>
<td>(r \cdot 0.398^*)</td>
<td>(r \cdot 0.231)</td>
</tr>
<tr>
<td>i. P</td>
<td></td>
<td>(r \cdot 0.039)</td>
<td>(r \cdot 0.308)</td>
</tr>
<tr>
<td>j. GH</td>
<td></td>
<td>(r \cdot 0.356)</td>
<td>(r \cdot 0.040)</td>
</tr>
<tr>
<td>DASS – 21:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. D</td>
<td></td>
<td>(r \cdot 0.165)</td>
<td>(r \cdot 0.033)</td>
</tr>
<tr>
<td>b. A</td>
<td></td>
<td>(r \cdot 0.435^*)</td>
<td>(r \cdot 0.321)</td>
</tr>
<tr>
<td>c. S</td>
<td></td>
<td>(r \cdot 0.330)</td>
<td>(r \cdot 0.158)</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) ** \(p < 0.01\); * \(p < 0.05\); \(n\) = number; \(r\) = Pearson’s product-movement correlation coefficient; C = Cervical; AP = Articular Pillar; TA = Tibialis Anterior; MPTT = Mechanical Pain Threshold Test; PA = Pressure Algometric; VAS = Visual Analogue Scale; NDI = Neck Disability Index; SF- 36 = The Short Form Health Survey; DASS – 21 = Depression (D) Anxiety (A) Stress (S) Scales.
APPENDIX 50

Correlations ($r$) between self-rated questionnaire and mechanical pain threshold measures for the chronic neck pain group ($n = 25$).

<table>
<thead>
<tr>
<th>SELF - RATED QUESTIONNAIRE MEASURES</th>
<th>MPTT (PA) MEASURES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cervical Spine Site (Most Painful Site)</td>
</tr>
<tr>
<td>VAS (Pain)</td>
<td>$r$ -0.402*</td>
</tr>
<tr>
<td>VAS (Stress)</td>
<td>$r$ 0.114</td>
</tr>
<tr>
<td>NDI</td>
<td>$r$ -0.478*</td>
</tr>
<tr>
<td>SF – 36:</td>
<td></td>
</tr>
<tr>
<td>a. PF</td>
<td>$r$ 0.484*</td>
</tr>
<tr>
<td>b. RL – PH</td>
<td>$r$ 0.252</td>
</tr>
<tr>
<td>c. RL – EP</td>
<td>$r$ -0.158</td>
</tr>
<tr>
<td>d. E / F</td>
<td>$r$ 0.374</td>
</tr>
<tr>
<td>e. EW – B</td>
<td>$r$ 0.054</td>
</tr>
<tr>
<td>f. SF</td>
<td>$r$ 0.280</td>
</tr>
<tr>
<td>g. P</td>
<td>$r$ 0.354</td>
</tr>
<tr>
<td>h. GH</td>
<td>$r$ 0.534**</td>
</tr>
<tr>
<td>DASS – 21:</td>
<td></td>
</tr>
<tr>
<td>a. D</td>
<td>$r$ 0.204</td>
</tr>
<tr>
<td>b. A</td>
<td>$r$ 0.281</td>
</tr>
<tr>
<td>c. S</td>
<td>$r$ 0.144</td>
</tr>
</tbody>
</table>

Sig. (2-tailed) ** $p < 0.01$; * $p < 0.05$; $n =$ number; $r =$ Pearson’s product-movement correlation coefficient; C = Cervical; AP = Articular Pillar; TA = Tibialis Anterior; MPTT = Mechanical Pain Threshold Test; PA = Pressure Algometric; VAS = Visual Analogue Scale; NDI = Neck Disability Index; SF- 36 = The Short Form Health Survey; DASS – 21 = Depression (D) Anxiety (A) Stress (S) Scales.

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REFERENCES


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