The Impact of the Cervical Lordosis on Postural Sway Parameters in Asymptomatic Participants.

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Dedication

This thesis is dedicated to my mother: Jeanette Mary (Robinson) Daffin, 12th April 1944 – 12th February 2010. Unfortunately, you passed away before your time, and just before I started this journey. You were with me during my two previous academic endeavours and watched me accept my degrees. This time you will walk with me inside my heart, I miss you so much. Your passing forced me to re-evaluate my shortcomings, and if I had not changed my ways, I would have never been able to undertake this thesis. You have been with me every step of the way through this journey, representing the greatest concerted academic effort in my life, your loving Son.
Abstract

The vertebral column is the defining characteristic of vertebrates. The human vertebral column can also be referred to as the spine, and constitutes the central element of the body’s axial skeleton. This structure has several key roles: (1) a stable support for the body, (2) kinematic motion and (3) protection of the spinal cord. Characteristically the spine consists of 33 vertebrae in series with 24 vertebrae separated from each other by 23 intervertebral discs. Five unique regions are identifiable within the spine with regions either comprising separate or fused vertebrae. Each vertebra is named according to the region and location from superior to inferior within its region: cervical (7 vertebrae C1–C7), thoracic (12 vertebrae T1–T12), lumbar (5 vertebrae L1–L5), sacral (5 fused vertebrae S1–S5) and coccygeal (4 [3 to 5] fused vertebrae).

The sagittal morphology of the spine is either naturally lordotic or kyphotic. Kyphotic curvatures possess concavities anteriorly and include the thoracic and sacroccocygeal regions. Lordotic curvatures possess convexities anteriorly, and include the cervical and lumbar regions. The naturally lordotic cervical region consists of seven vertebrae, two extremely specialised vertebrae are located superiorly including the atlas and axis, while below the axis are five standard vertebrae. The cervical spine is highly mobile, and this region is frequently described in conjunction with the skull and is referred to as the craniocervical region due to the complex osteokinematic interrelationships.
Functional postural control is an essential characteristic required to successfully accomplish activities of daily living. Upright postural control and the maintenance of equilibrium is exceedingly complex and involves interpreting afferent information and coordinating appropriate efferent motor patterns in response. Balance assessments can be performed statically during stance or dynamically as a result of bipedal locomotion, both requiring distinctly different neurological integrations to preserve the body’s centre of mass (CoM) over their respective bases of support. Postural sway is the measurable criterion investigating the excursion of the body’s CoM relative to the base of support, with minimal excursion reflecting greater postural control.

The apparatus principally used to investigate postural control is the force platform; it accurately measures the ground reaction forces generated by the motion of the body CoM. This data are used to generate centre of pressure (CoP) parameters which are considered to be the gold standard for assessing postural control. Accordingly, CoP parameters serve many purposes, primarily allowing researchers to investigate differences between asymptomatic and pathological groups, and substantiate findings of applied rehabilitative interventions. Over the past two decades it has been independently concluded that significant relationships exist between CoP parameters of asymptomatic, nonspecific neck pain (NSNP) and whiplash associated disorder (WAD) participants. Asymptomatic participants exhibit greater postural control when compared to both NSNP and WAD participants, while WAD participants have reduced postural control in relation to the other two cohorts.
As mentioned, the majority of the research within this domain has concentrated on differences between asymptomatic and pathological groups, with limited research being conducted into the differences within an asymptomatic sample’s postural control. Several authors have identified that decreased postural control within an asymptomatic sample can be attributed to forward head posture (FHP), one common altered postural position typically evaluated by external photographic measures. Importantly, recent evidence indicates that cervical non-lordotic subtypes promote the biological mechanisms responsible for progressing a multitude of cervical osseous and myelopathic degenerative conditions. A comprehensive literature review within postural control domain, in particular the asymptomatic discipline, failed to identify a detailed functional etiology describing the mechanistic or neural mechanism by which an asymptomatic individual may transition into an early NSNP sufferer.

An asymptomatic classification is only present when no symptoms typically associated with a particular condition are presently displayed by the individual. In the medical field, an individual may be the carrier for a disease or infection but experience no symptoms, similar to the phenomenon observed in asymptomatic postural control. It is concerning that presently asymptomatic cervical non-lordotic subtypes exist in abundance within the population, given this altered postural position promotes future degenerative conditions that are significantly associated with higher levels of chronic pain syndromes. Similarly, differences in postural control are evident in asymptomatic samples, with certain participants demonstrating increased postural control while those with altered cervical postures (FHP) display decreased postural control and have none of the symptoms consistent with NSNP. Questions have been raised concerning the possibility of using the differences between CoP parameters as novel biomarkers to clinically identify early pathology.
Accordingly, if we are to amend our current gap in knowledge concerning the mechanistic etiology of asymptomatic transition into pathology, determining accurate asymptomatic CoP parameters for all cervical subtypes may provide the necessary data capable of achieving this goal.
Declaration of Originality

I declare that the presented thesis is solely the account of original research performed by myself. This research contains no material written or formerly published by another individual except were acknowledgement of appropriate references have been made. All jointly authored work contained within the body of thesis has been clearly acknowledged. The content of my thesis is the final culmination of the findings identified during the processing of the research data collected since the commencement of my higher degree by research candidature.

Contained within the pages of this thesis is absolutely no material previously submitted for a Doctor of Philosophy degree at any other tertiary institution or university.

Lee Daffin PhD Candidate

Date: 2nd May 2018.
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The journey undertaken to submit this higher degree by research thesis started approximately two decades prior to its final submission. It required a clinical education cultivated in numerous Universities including Southern Cross University, Macquarie University, Sydney University and its affiliated Cumberland Campus, University of New South Wales and the University of the Sunshine Coast. My clinical chiropractic insight, patient relationships, empathetic realisations and internal fortitude formed my cornerstone enabling the foundations of this project to take hold, vigorously flourish and weather the deleterious events that life threw at me during this project. It’s time to let the parts tell the whole.

To my parents, Roger and my late mother Jeanette, your loving support allowed me to commence, continue and complete both my Bachelor’s and Master’s degree programs. The financial burden of my early academic journey would have been too overwhelming to have even contemplated beginning without your substantial contribution to my life. The completion of this higher degree by research thesis would not have been possible without the continued support of my father, who allowed me to dedicate the enormous amount of time needed to finish this journey. In their own unique ways, my parents are perfect examples of unconditional love and support. My family, all I can say is thank you from the bottom of my heart. Gabrielle, your ongoing unquestionable support and continuing belief in me has helped me get through some difficult times during this journey. You have lifted me up on many occasions helping me to stay positive and focused on the end goal, the completion of this project.
To my two children Ella and Harley, I regret the time that I have lost to you both during a period in your lives when I should have spent a considerably larger amount of time with you both. A father’s role is to provide, support and nurture the development of his children guiding them into adulthood; unfortunately, this project has reduced my ability to perform this vital task. As a family we decided to begin this journey for one reason, the future security of the family unit and the opportunities a PhD would bring within a tertiary institution. The privilege of make a reasonable living in a field of science I love will be worth the sacrifice. It will allow me to finish my working life in an occupation that provides personal fulfilment and potentially more quality time to enjoy my family. This journey has opened my eyes and, in turn my family’s, to the true nature of the modern academic environment, its pros and cons. However, the cons in the system are lessened when the true essence of the institution is realised. Imparting a lifetime’s worth of knowledge to the next generation is what I now consider to be the noblest profession I have ever being involved in and one I absolutely love with a passion.

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### Abbreviations

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<th>Full Form</th>
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<tbody>
<tr>
<td>aCROM</td>
<td>active cervical range of motion</td>
</tr>
<tr>
<td>AMA</td>
<td>American Medical Association</td>
</tr>
<tr>
<td>ARA</td>
<td>absolute rotation angle</td>
</tr>
<tr>
<td>A/P (Range)</td>
<td>anterior/posterior (range)</td>
</tr>
<tr>
<td>APL</td>
<td>atlas plane line</td>
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<tr>
<td>aSROM</td>
<td>active shoulder range of motion</td>
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<tr>
<td>ATHM</td>
<td>anterior translation of the head measure</td>
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<tr>
<td>BoS</td>
<td>base of support</td>
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<tr>
<td>CDL</td>
<td>centroid determination line</td>
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<tr>
<td>CFNT</td>
<td>cerebellar finger-to-nose test</td>
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<tr>
<td>CNS</td>
<td>central nervous system</td>
</tr>
<tr>
<td>CoM</td>
<td>centre of mass</td>
</tr>
<tr>
<td>CoP</td>
<td>centre of pressure</td>
</tr>
<tr>
<td>COR</td>
<td>cervico-ocular reflex</td>
</tr>
<tr>
<td>CS</td>
<td>compliant surface (on force platform)</td>
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<tr>
<td>CSh</td>
<td>conformational shape</td>
</tr>
<tr>
<td>CVA</td>
<td>craniovertebral angle</td>
</tr>
<tr>
<td>DALY</td>
<td>disability adjusted life year</td>
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<tr>
<td>DCM</td>
<td>degenerative cervical myelopathy</td>
</tr>
<tr>
<td>EMPA</td>
<td>external measures of postural alignment</td>
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<tr>
<td>EPM</td>
<td>external photographic measures</td>
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<tr>
<td>FCT</td>
<td>foraminal compression testing</td>
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<td>FHP</td>
<td>forward head posture</td>
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<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>FS</td>
<td>firm surface (on force platform)</td>
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<tr>
<td>FST</td>
<td>functional squat test</td>
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<tr>
<td>GBD</td>
<td>global burden of disease</td>
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<tr>
<td>GK-type</td>
<td>global kyphotic type</td>
</tr>
<tr>
<td>ICC</td>
<td>intraclass correlation coefficient</td>
</tr>
<tr>
<td>IVD</td>
<td>intervertebral disc</td>
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<tr>
<td>IVDL</td>
<td>intervertebral disc lines</td>
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<tr>
<td>JPS</td>
<td>joint position sense</td>
</tr>
<tr>
<td>L-type</td>
<td>lordotic type</td>
</tr>
<tr>
<td>LHTA</td>
<td>lateral head tilt angle</td>
</tr>
<tr>
<td>LR</td>
<td>likelihood ratio</td>
</tr>
<tr>
<td>MDC</td>
<td>minimal detectable change</td>
</tr>
<tr>
<td>MHTA</td>
<td>mastoid head tilt angle</td>
</tr>
<tr>
<td>MIMT</td>
<td>manual isometric muscle testing</td>
</tr>
<tr>
<td>mmHg</td>
<td>millimetres of mercury</td>
</tr>
<tr>
<td>MRI</td>
<td>magnetic resonance image</td>
</tr>
<tr>
<td>MSK</td>
<td>musculoskeletal</td>
</tr>
<tr>
<td>MVeL TEx</td>
<td>mean velocity total excursion</td>
</tr>
<tr>
<td>n</td>
<td>number (of participants)</td>
</tr>
<tr>
<td>NDI</td>
<td>neck disability index</td>
</tr>
<tr>
<td>NSNP</td>
<td>non-specific neck pain</td>
</tr>
<tr>
<td>OA</td>
<td>osteoarthritis</td>
</tr>
<tr>
<td>OCI</td>
<td>obliquus capitis inferior</td>
</tr>
<tr>
<td>OCS</td>
<td>obliquus capitis superior</td>
</tr>
<tr>
<td>OKR</td>
<td>optokinetic reflex</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<td>--------------</td>
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</tr>
<tr>
<td>pCROM</td>
<td>passive cervical range of motion</td>
</tr>
<tr>
<td>PE</td>
<td>physical examination</td>
</tr>
<tr>
<td>PSQ</td>
<td>postural sway questionnaire</td>
</tr>
<tr>
<td>PVBL</td>
<td>posterior vertebral body line</td>
</tr>
<tr>
<td>PVBM</td>
<td>posterior vertebral body margin</td>
</tr>
<tr>
<td>RCPma</td>
<td>rectus capitis posterior major</td>
</tr>
<tr>
<td>RCPmi</td>
<td>rectus capitis posterior minor</td>
</tr>
<tr>
<td>ROM</td>
<td>range of motion</td>
</tr>
<tr>
<td>RRA</td>
<td>relative rotation angle</td>
</tr>
<tr>
<td>RS-type</td>
<td>reverse sigmoidal type</td>
</tr>
<tr>
<td>S(n)</td>
<td>session (number)</td>
</tr>
<tr>
<td>S-type</td>
<td>sigmoidal type</td>
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<tr>
<td>SF-36</td>
<td>36-item short form health survey</td>
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<tr>
<td>SPSS</td>
<td>statistics package for the social sciences</td>
</tr>
<tr>
<td>St-type</td>
<td>straight type</td>
</tr>
<tr>
<td>TEx</td>
<td>total excursion</td>
</tr>
<tr>
<td>UCGA</td>
<td>upper cervical gaze angle</td>
</tr>
<tr>
<td>USC</td>
<td>university of the sunshine coast</td>
</tr>
<tr>
<td>VOR</td>
<td>vestibulo-ocular reflex</td>
</tr>
<tr>
<td>WAD</td>
<td>whiplash associated disorder</td>
</tr>
<tr>
<td>YLD</td>
<td>years lived with disability</td>
</tr>
<tr>
<td>YLL</td>
<td>years of life lost</td>
</tr>
<tr>
<td>95% CC</td>
<td>95% confidence circle</td>
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</table>
Original Research Published in Peer-Reviewed Journals


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Chapter 1

1.1 Research Questions

The facts accumulated from the interrelated literature on the cervical spine and postural control during this research project’s confirmation process, provided the impetus that allowed this thesis to develop. During this thesis the primary research question will be explored and answered, as will several additional secondary questions.

1.1.1 Primary research question

- Do asymptomatic participants exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype, show evidence of decreased postural control?

1.1.2 Secondary research questions

- Are the current published physical examination eligibility instruments used to include or exclude participants effective, when establishing an asymptomatic research sample to investigate the cervical spine?
- Are the photogrammetric techniques used for determining stationary neutral craniovertebral postures transferable during radiographic acquisition?
- Are there differences in outcomes for stationary neutral craniovertebral posture quantification between common photogrammetric techniques and those involving direct measures through radiographic acquisition?
  - If so, how comparable are data collected using both techniques?
• During radiological subtype classification, are the different methodologies consistently classifying each subtype, or are potential inter-methodological inconsistencies affecting subtype classification?

• Do the commonly cited radiological measures of sagittal cervical alignment act as potential indicators of postural control?

• In an asymptomatic sample, is the level of postural control within a cervical non-lordotic sample similar to those established in non-specific neck pain (NSNP) samples during comparable testing protocols?

• Is the reliability of the current CoP collection protocols amenable when formulating potential novel baseline biomarkers, that retain the capacity of being incorporated into a theoretical longitudinal study designed to identify possible early clinically cervical pathology?

• If asymptomatic participants exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype show evidence of maladaptive decreased postural control, how does the literature clarify a potential positive finding?
1.2 Addressing a Mounting Problem: The Benefit of this Research Project

The human musculoskeletal (MSK) system manifests morbidity and dysfunction exceedingly well (Escorpizo, 2014; Hoy, Geere, Davatchi, Meggitt, & Barrero, 2014; Milte & Crotty, 2014; Shahar & Sayers, 2016). It is imperative, within the 21st century, that the global health care system develops and implements adequate management strategies to tackle the multifactorial issues associated with MSK disorders. Currently facing and afflicting humanity is a magnitude of health challenges associated with the spine, and, in particular, the cervical region (Carroll, Hurwitz, et al., 2008; Hay, 2017). Modern medical advancements have increased global life expectancy and decreased mortality rates. The consequence of an older population is the perpetuation of, and apparently unavoidable increases in, disabling non-fatal diseases, forcing individuals to spend a significant proportion of their lives with functional health loss (Hay, 2017; Schutte, 2017).

The prevalence of disabling non-fatal diseases surges sharply as we age, therefore an ageing population places greater demands on services that are potentially costlier than the interventions that brought about the reductions in mortality (Hay, 2017). The global burden of disease study (GBD) is an ongoing comprehensive, comparative, epidemiological study investigating mortality and morbidity trends across the globe’s population since 1990 (Schutte, 2017). Indicators are used to express health loss due to both fatal and non-fatal diseases, and the disability adjusted life year (DALY) expresses the overall disease burden as the number of years lost to chronic illness, disability or early death. The DALY is the sum of two components: the years lived with disability (YLD) and the years of life lost (YLL) due to premature death; hence, one DALY is equivalent to one year of healthy life lost (Figure 1.1) (Murray, 1994; A. D. Woolf, Vos, & March, 2010).
Most of the data used within the GBH studies to evaluate the severity distributions of non-fatal diseases are sourced from sparse studies conducted in high income countries. This limitation has the possibility of underestimating YLD in low to middle income countries. Reporting global severity distributions represents a systematic error and potential bias, therefore attempts are made to adjust for this concern and represent geographical variations with greater precision (Hay, 2017; Schutte, 2017). It is reasonable to assume the true nature and magnitude of the severity of neck pain within the global population is misrepresented and potentially greater in low to middle income countries due to under diagnosis, late diagnosis and minimal reporting (Schutte, 2017).
1.3 The Focus of this Research Project

As mentioned, since 1990 the mortality rates associated with most diseases have decreased; unfortunately, the same cannot be said for most of their corresponding DALY (Schutte, 2017) and YLD (Hay, 2017) rates. In more than half of the 195 countries and territories involved in the GBH study, participants ranked the YLD related to neck pain within the top ten identified conditions, a shift from 8th position in 1990 to the 6th largest GBH contributor in 2016. Neck pain associated YLD increased 41.2% from 1990 to 2006, then a further 21.9% from 2006 to 2016 with approximately 29 million YLD directly contributed to neck pain globally in 2016 (Hay, 2017). During the 2010 GBH study, 291 health-related conditions where studied. When ranking neck pain by the YLD it was identified as the 4th largest disability burden afflicting the global population’s overall health status (Hoy et al., 2014; March et al., 2014). Between 1990 and 2016, DALYs associated with neck and lower back pain transitioned from 13th to the 4th largest GBD position, increasing 29.8% from 1990 to 2006 and then a further 19.3% from 2006 to 2016 (Schutte, 2017).

Figure 1.2. Proportion of YLD for each of the musculoskeletal disorders, global burden of disease study 2010, adapted from (March et al., 2014).
Neck pain as an isolated condition was ranked 21st for DALYs out of the 291 conditions in the 2010 GBH study (Hoy et al., 2014; March et al., 2014). It is evident an ever-increasing trend is present within the DALY and YLD globally. Considering non-fatal diseases separately from fatal diseases, disorders involving the MSK system are ranked 2nd overall in the GBH as substantial contributors to morbidity, just behind mental illness (Speerin et al., 2014). As Figure 1.2 indicates, the proportion of YLD for all the MSK disorders identifies the two largest burdens to be (1) lower back pain (49.6%) and (2) neck pain (20.1%). These are followed by a heterogeneous collection of other MSK disorders (17.3%), osteoarthritis (OA) (10.5%), rheumatoid arthritis (2.3%) and gout (0.1%) (Hay, 2017; March et al., 2014).

The MSK burden is similar in both high income and low to middle income countries (Mody & Brooks, 2012), with the physical, social and economic costs practically incalculable; however, annual estimates have been reported in the hundreds of billions of dollars globally (Dall, Gallo, Koenig, Gu, & Ruiz, 2013; Hoy, Protani, De, & Buchbinder, 2010). The aetiology of non-specific neck pain (NSNP) is multifactorial, and ambiguous at best, with several varied viewpoints expressed. Some research groups advocate a local pathologic causative mechanism which is able to be identified and managed, while others maintain the problem is primarily nonorganic, constituting psychological and social constructs (Carroll, Hurwitz, et al., 2008; Guzman et al., 2008; Hoy et al., 2010; A. D. Woolf et al., 2010). However, the biopsychosocial model, as depicted in Figure 1.3, is the conceptual framework embraced by the International Classification of Functioning Disability and Health (World Health Organization, 2001).
Pain is a purely individual, subjective, conceptualised phenomenon constituting an undesirable sensory or emotional experience accompanying actual or potential tissue damage (Bonica, 1979; Guzman et al., 2008). The presence and severity of pain is generally self-reported, and unfortunately the accuracy of this reporting mechanism cannot be validated or measured against external criteria (Guzman et al., 2008). Pain manifests itself because of three quite different mechanisms: firstly, it protects the biological system by distinguishing noxious stimuli; secondly, inflammatory pain following tissue damage suppresses physical contact and movement, thus, promoting recovery; and thirdly, there is non-protective and maladaptive pathological pain resulting from damage, disease or abnormal functioning of the nervous system (C. J. Woolf, 2010).
1.4 The Benefit of Addressing the Problem

Neck pain is defined as pain being experienced in the neck, as depicted in Figure 1.4A and B, for at least 1 day with or without referral into either or both upper limbs (March et al., 2014), and head and/or trunk (Guzman et al., 2008). It is generally accepted that neck pain is not a single episode with permanent symptomatic resolution, instead it runs a chronic episodic course with relapses and remission commonly experienced in 50 to 85% of individuals after the initial episode (Carroll, Hogg-Johnson, et al., 2008; Guzman et al., 2008; Hoy et al., 2010; A. D. Woolf et al., 2010).

*Figure 1.4. The anatomic regions where the presence of pain is classified as neck pain. A. Posterior. B. lateral, mandated by the 2000 - 2010 Task Force on Neck Pain, adapted from (Guzman et al., 2008).*
Tackling neck pain is imperative if the GBH is anything to go by, and current knowledge must contribute to the development and implementation of high quality studies to fill the gaps in our knowledge base, in particular the interactions associated with the physical factors that potentiate the risk of developing neck pain (Carroll, Hurwitz, et al., 2008). Neck pain must commence at a point in time, identifying asymptomatic biomarkers prior to this point was one premise underlying this research project, possibly providing a foundation to develop and implement asymptomatic therapies capable of preventing this escalating problem at its source. Idiopathic adolescent spinal pain is one key source of this problem, and a significant public health issue affecting around 12% to 35% of school age children (Molina et al., 2017). The first episode of neck pain is typically experienced between 10 and 19 years of age, and its prevalence approaches that of adults (mean: 23.1%) by approximately 18 years of age (Hoy et al., 2010; Jeffries, Milanese, & Grimmer-Somers, 2007).

Neck pain seemingly occurs as part of a normal adolescent’s life, with sufferers typically developing a mature chronic episodic condition (Hoy et al., 2010; Jeffries et al., 2007). By virtue of the perceived health statue within the adolescent population, strategies to identify or limit early dysfunction are neither developed nor prioritised effectively (P. M. Clark & Ellis, 2014; F. M. Gore et al., 2011; Speerin et al., 2014; A. D. Woolf et al., 2010). A recent report has identified that significantly reduced pain thresholds are experienced in adolescents with idiopathic MSK pain when compared to asymptomatic adolescents. While this finding is alarming in its own right, it has been further suggested that these symptomatic adolescents may also subjectively experience MSK pain at levels that are more intense and unpleasant (Molina et al., 2017).
Children, adolescents and university students are increasingly exposed to sedentary lifestyles, mainly due to the rapidly growing exposure of screen-based activities on computers (Brink & Louw, 2013) and smartphones (Guan et al., 2016; Toh, Coenen, Howie, & Straker, 2017). Regardless of gender, clear evidence exists indicating that these populations are at risk of developing neck pain while using any form of modern electronic device, either sitting (Brink, Louw, Grimmer, & Jordaan, 2014; Brink & Louw, 2013; Straker, Smith, Bear, O'Sullivan, & de Klerk, 2011) or standing (Guan et al., 2016; Toh et al., 2017). Both cervical and cervicothoracic flexion assumed during any prolonged, static postural loading situations adversely affects cervicothoracic erector spinae activity and potentially facilitates cervical overuse sprain/strain syndromes (Brink & Louw, 2013; Straker et al., 2011).

University students who use electronic devices while assuming static postures for as little as 20 minutes a day, irrespective of the educational, leisure or social setting, risk MSK disorders with reports of neck pain within samples ranging from 52.8% (Dockrell, Bennett, & Culleton-Quinn, 2015) to 70% (Woo, White, & Lai, 2016). Historically attitude towards MSK health have unfortunately been reactive, not proactive. The opportunities to promote lifelong MSK health, and thus limit or prevent neck pain in the young asymptomatic population, have not been fully exploited (P. M. Clark & Ellis, 2014; F. M. Gore et al., 2011). Recognising an asymptomatic neck statue requires all the intervening questions regarding neck pain and/or any neck pain associated disorders to be answered negatively (Guzman et al., 2008). Fundamentally, MSK health is much more than simply the absence of symptoms; it requires multiple factors to come together in a seamless interrelationship, and these factors include, but are not limited to, bones, joints, muscles and the nervous system as indicated in Figure 1.5 (P. M. Clark & Ellis, 2014).
Figure 1.5. Factors comprising musculoskeletal health, adapted from (P. M. Clark & Ellis, 2014).

The opportunity to clinically identify early pathology and validate a potential novel biomarker concerning the transitional phase associated with non-specific neck pain (NSNP) requires a clear understanding of the factors comprising MSK health (P. M. Clark & Ellis, 2014; Konig, Taylor, Baumann, Wenderoth, & Singh, 2016). A naturally lordotic alignment in the cervical spine is considered optimal for functionality and health-related quality of life factors (Ames et al., 2013; Nouri, Tetreault, Singh, Karadimas, & Fehlings, 2015; Shahar & Sayers, 2016). Importantly, recent evidence indicates that non-lordotic subtypes promote the pathogenesis and rate of progression associated with a multitude of cervical osseous and myelopathic degenerative conditions (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015). Two landmark systematic reviews have independently concluded that statistically significant differences exist between the centre of pressure (CoP) parameters of asymptomatic (control), NSNP and whiplash associated disorder (WAD) participants (Ruhe, Fejer, & Walker, 2011; Silva & Cruz, 2013).
These two reviews indicate asymptomatic participants have been shown to exhibit increased postural control when compared to both NSNP and WAD participants, while WAD participants have significantly less postural control than the other two cohorts. Recently researchers have started to assess links between postural conditions and postural control. Importantly, researchers have linked FHP, one of the common non-lordotic postural conditions, to decreases in postural control in asymptomatic populations (Kang et al., 2012; J. H. Lee, 2016). Although these two studies quantified postural control using standard CoP assessment techniques, they determined FHP through external photographic measures (EPM), an approach that may not provide critical information on the true nature of the underlying cervical vertebral alignment (Oliveira & Silva, 2016).

Additionally, gross measures of cervical posture such as those assessed using EPM fail to account for the numerous alternative cervical non-lordotic conditions that can only be classifiable radiologically (Ames et al., 2013; D. D. Harrison, Janik, Troyanovich, & Holland, 1996; Ohara, Miyamoto, Naganawa, Matsumoto, & Shimizu, 2006). Alarmingly, recent research highlighted that non-lordotic subtypes are common within an asymptomatic population of young adults (Faline, Szadkowski, Berthonnaud, Fièrè, & Roussouly, 2007; Le Huec, Demezon, & Aunoble, 2015; Shahar & Sayers, 2016). The question remains as to whether these changes may be used as novel biomarkers to clinically identify early pathology (Konig et al., 2016).
1.5  Research Significance and Future Directions

The facts raised throughout this chapter provide the impetus for the primary research question.

1.5.1  Primary research question

- Do asymptomatic participants exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype, show evidence of decreased postural control?

This research project was undertaken to investigate the primary research question concerning a sample selected primarily based on its asymptomatic health status, possibly exhibit decreased postural control in participants possessing only the cervical non-lordotic subtypes. Achieving this outcome would require accurate cervical subtype identification then classification prior to postural control trials. The successful demonstration of decreased postural control in asymptomatic participant with conformational cervical subtypes other than a natural cervical lordosis could advance and strengthen the knowledge concerning the inconsistent postural control CoP parameters observed in asymptomatic samples. Objective evidence related to this phenomenon may assist future research endeavours to potentially unravel the complex multifactorial mechanisms associated with the etiology of NSNP. Positive findings may stimulate discussions concerning asymptomatic neural coordination in the early phase of NSNP transition, and potentially lead to a clinical biomarker capable of distinguishing an individual at risk of transitioning into this debilitating disorder.
1.6 The Organisation Structure of the Thesis

This thesis consists of several chapters detailing the step wise progression of this research project from the literature review to the future research directions. The literature review, Chapter 2, serves to identify the current theoretical and methodological material available within the relevant domains. It pulls together many separate studies within our current knowledge base and provides context regarding how these studies came together to substantiate and finally answer the primary research question. It does not report new or original work undertaken as part of this project. The cervical spines health status is a key factor that underpins the fundamental premise of the primary research question. Chapter 3 is presented in four primary sections, leading with the human ethics approval process followed by the various recruitment sources to acquire 150 asymptomatic participants in the selected age bracket 18 to 30. The protocols undertaken during this research project are also detailed and discussed. A detailed description concerning the accepted eligibility instruments and methodologies used to include or exclude participants into an asymptomatic research sample concluded Chapter 3.

Chapter 4 details the photogrammetric protocols used to acquire, measures and evaluate natural stationary neutral craniovertebral postures. Chapter 4 investigates whether photographic techniques are reliably transferable during radiological acquisition. Transferability then comparability will allow accurate radiological identification of each participant’s neutral craniovertebral posture. The potential for systematic bias to adversely influence cervical subtype classification is then explored in Chapter 5.
The presence of inter-methodological inconsistencies may lead to a systematic error while classifying each cervical subtype, affecting lordotic and non-lordotic group allocation. Chapter 6 discusses the possibility of common sagittal cervical radiological measures acting as potential indicators of postural control. Explained in detail within Chapter 6 is the rigorous postural control protocols adhered to throughout this study that permitted the CoP data to be recorded. The CoP findings contained within Chapter 6 allow the primary research question to be answered. Chapter 7 is the culmination of this thesis, bringing the many components of this research project together and discussing the primary research finding that asymptomatic participants exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype show evidence of decreased postural control.

Future applications pertaining to the findings of this thesis are outlined in Chapter 8. Discussions within Chapter 8 use the relevant literature together with the thesis findings to facilitate the rationale behind our interpretations. Several theoretical viewpoints are investigated, such as neurological adaptations associated with cervical non-lordotic subtypes, similarities between asymptomatic cervical non-lordotic and NSNP CoP parameters during comparable testing protocols, and the use of CoP analyses to function as objective biomarkers capable of clinically identifying early transitional cervical pathology.
Chapter 2

2.1 Introduction

As detailed in Chapter 1, this chapter identifies theoretical material and methodological protocols available within the current knowledge base that provides the context for the primary research question. Many separate studies were reviewed within relevant domains including, but not exclusively limited to, spinal and cervical alignment, osseous morphology, spinal kinematics, aberrant proprioceptive afferent input, non-specific (idiopathic adolescent) neck pain, traumatic MSK pain, pain associated postural control and asymptomatic postural control.

Underpinning the fundamental premise of the primary research question is the health status of cervical spines, and the effect alterations in normal alignment have on the cervical spine’s ability to coordinate appropriate neurological integrations during standing postural control. Corroborating scientific evidence exists within the literature to support the primary research question.

This chapter identifies and discusses pertinent information within the relevant literature. It transitions through: normative cervical parameters, mechanisms responsible for cervical non-lordotic subtypes, general and specific age-related degenerative characteristics related to non-lordotic subtypes, the effect non-lordotic subtypes have on proprioception, impaired proprioception in NSNP, postural control parameters linked to both traumatic and NSNP, and postural control parameters in asymptomatic (control) participants.
Methodological protocols investigating techniques in domains such as photogrammetric, radiographic and postural balance are also discussed in this chapter, but detailed descriptions related to those methodological protocols are presented in following chapters where their relevance is better served. This chapter will briefly investigate the potential neurological mechanisms responsible for decreased postural control, ensuring completeness of the reviewed literature for this research project. The culmination of this chapter is a succinct synopsis that brings together the reviewed literature while identifying significant issues that have been identified throughout the course of this review.
2.2 Search Strategies and Literature Selection Criteria

To identify literature with specific relevance to this project, a database of domain-appropriate terms was created. This strategy allowed the many available electronic databases to be systematically searched. Subsequently, these terms were entered into several electronic databases chosen to be the most relevant for this project; these were SCOPUS, Google Scholar, Web of Science, PubMed, Dissertations catalogued on TROVE and the University of the Sunshine Coast’s (USC) library.

The selected databases were appropriate to generate the quality and quantity of peer-reviewed literature. The literature review was updated throughout the entire duration of this project, allowing newly reported findings to be incorporated. The domain-appropriate search terms were narrowed to include literature that predominately involved human studies; however, specific non-human neurological literature is clearly identified when referenced.

To improve the success rate while searching, amendments were made to the domain appropriate terms when deemed appropriate. Cited references appearing within relevant literature previously identified through the domain-appropriate search terms were obtained as well. Several key authors identified within systematic reviews and individual peer-reviewed journals were also routinely investigated via SciVal to identify pertinent literature previously not obtained, thus ensuring an all-inclusive search strategy attempting to include all relevant literature.
2.3 Normal Spinal Anatomy

Hippocrates (460–370 B.C.), the father of modern medicine, is credited with the first description of standardised human spinal curvature (Roussouly & Pinheiro-Franco, 2011). The coronal perspective is naturally straight; however, the sagittal morphology is distinctly different with either naturally lordotic or kyphotic regions (D. E. Harrison, Harrison, Trojanovich, & Harmon, 2000; Roussouly & Pinheiro-Franco, 2011). Kyphotic curves are concave anteriorly and include the thoracic and sacrococcygeal regions, whereas lordotic curves are convex anteriorly and include the cervical and lumbar regions. The human vertebral column can also be referred to as the spine; it comprises five anatomical regions and constitutes the central element of the body’s axial skeleton (Moore, Dalley, & Agur, 2013; Tortora & Derrickson, 2008). The spine has several key roles: (1) a stable support for the body, (2) kinematic motion and (3) protection of the spinal cord (Moore et al., 2013; Neumann, 2013).

There are generally 33 individual vertebrae, of which 24 possess articular ability since they are separated from each other by 23 intervertebral discs. Descending distally from the cranium, each vertebra is named according to the region and the location (superior to inferior) within its specific region. There are three primary articulating spinal regions, with each anatomical region typically exhibits a specific number of vertebrae. The three regions from cranial to caudal are classified as: cervical (7 vertebrae C1–C7), thoracic (12 vertebrae T1–T12) and lumbar (5 vertebrae L1–L5). No motion is available within the fused sacral (5 fused vertebrae S1–S5) and coccygeal (4 [3 to 5] fused vertebrae) regions; however, a very small degree of motion is present between these two regions (Moore et al., 2013; Tortora & Derrickson, 2008).
2.4 Sagittal Spinal Alignment and Balance: An Evolving Interdependency

To maintain erect, vertical, bipedal posture, alternating sagittal curves are fundamentally essential (Moore et al., 2013; Roussouly & Pinheiro-Franco, 2011); however, there is a wide variation in the overall sagittal geometric shape, and little agreement exists on the exact segmental levels in which transition occurs between regions (D. E. Harrison, Harrison, Troyanovich, et al., 2000; Roussouly, Gollogly, Berthonnaud, & Dimnet, 2005). When homogenous spinal characteristics are challenged and debated, only the general geometric shape of the three curves is commonly advocated and agreed upon (D. E. Harrison, Harrison, Troyanovich, et al., 2000). The inflection point is the location at which transition from lordosis to kyphosis occurs or vice versa (Figure 2.1) (Roussouly & Pinheiro-Franco, 2011). Classically, this point is situated between C7/T1 (lordosis to kyphosis) and T12/L1 (kyphosis to lordosis); however, this firm belief is overly simplistic as this point is completely intra-individualised due to varied regional vertebral contributions existing within the human spine (Roussouly et al., 2005).
Sagittal spinopelvic alignment was investigated in symptomatic adults aged 18 to 48 ($n = 160$), concluding that spinopelvic alignment is exceedingly variable (Roussouly et al., 2005). This research reported variability within the sacral slope ranging from 20° to 65°, while the lumbar lordosis ranged from 41° to 82°. However, contrary to accepted convention, an alarming finding was the number of vertebrae arranged in the lordotic alignment of the lumbar region, ranging from either 1 to 8 vertebrae. Additionally, sagittal spinopelvic alignment research in asymptomatic adults aged 40 to 82 ($n = 100$) concluded that, when interpreting alignment data, it is more beneficial to consider the range instead of the mean, as substantial variations exist within the human spine (Gelb, Lenke, Bridwell, Blanke, & McEnery, 1995). An asymptomatic investigation into sagittal parameters in adults aged 20 to 70 ($n = 300$) came to the same conclusion regarding the existence of tremendous spinal variations within the human spine (Vialle et al., 2005).
An investigation into asymptomatic children aged 3 to 18 \((n = 341)\) concluded that sagittal spinopelvic alignment parameters are comparable to the substantial variations observed in adult populations (Mac-Thiong, Labelle, Berthonnaud, Betz, & Roussouly, 2007). During an investigation into global sagittal spinal alignment within adolescents aged 10 to 13 \((n = 1196)\), it was shown significant variations existed throughout the spine globally, including the pelvis’s sagittal alignment parameters (Dolphens et al., 2012). Of notable interest within this adolescent population was the reporting that large variations in the thoracolumbar inflection point were identified; ideally it should be located at T12-L1. However, the highest inflection point was noted at T8-9 and the lowest at L3-4, conferring with the research findings of Roussouly et al. (2005) that adult spines exhibit extremely varied regional vertebral contributions.

The cervical region is considered to exhibit a naturally lordotic alignment pattern (D.E. Harrison, Harrison, Troyanovich, et al., 2000) consisting of seven vertebrae; the atlas (C1) and axis (C2) are two extremely specialised vertebrae located superiorly within this region, while below the axis are five standard vertebrae (C3 - C7) (Moore et al., 2013). The cervical spine is highly mobile, and this region is frequently described in conjunction with the skull. Together they are referred to as the craniocervical region due to their complex osteokinematic inter-relationships (Neumann, 2013). It has been shown that the cervical lordosis increases with respect to age, and this compensatory mechanism is a direct response to an increase in the aging thoracic kyphosis along with a requirement to maintain a level line of sight (Hardacker, Shuford, Capicotto, & Pryor, 1997; Kuntz IV, Levin, Ondra, Shaffrey, & Morgan, 2007). Although the cervical region is considered lordotic, several research groups have confirmed that regional alignment variability exists within asymptomatic participants. (Dolphens et al., 2012; Le Huec et al., 2015; Mac-Thiong et al., 2007; Vialle et al., 2005).
Hardacker et al. (1997) investigated sagittal cervical alignment in asymptomatic participants aged 20 to 70 \((n = 100)\), concluding 39% of the participants displayed kyphotic segments greater than 5°, while multiple level kyphosis was present in 4% of the participants. Visscher and Naeije (1998) investigated sagittal cervical alignment in asymptomatic participants aged 20 to 31 \((n = 54)\), concluding alignment variability is common place within the cervical region. Visscher and Naeije (1998) segregated participants into three groups depending on their alignment characteristic: (1) lordosis, (2) hypolordosis and (3) kyphotic. The cervical lordotic group displayed approximately an even gender match \((n = 10)\), while females \((n = 13)\) dominated the cervical kyphotic group and males \((n = 13)\) dominated the cervical hypolordotic (straight) group.

C. S. Lee et al. (2012) investigated sagittal spinal alignment in asymptomatic children aged 3 to 20 \((n = 181)\). Once segregated into three groups similar to Visscher and Naeije (1998) methodology, it was determined 109 (62%) participants exhibited either hypolordotic or kyphotic cervical alignment. Alarmingly, 80 (44.2%) of the 181 participants displayed a kyphotic cervical alignment. Recently, Le Huec et al. (2015) investigated sagittal cervical spinal alignment in asymptomatic participants age 18 to 76 \((n = 106)\), confirming one third \((34\%)\) of the participants exhibited kyphotic cervical spinal alignment. This research team suggested that post-traumatic muscle spasm was not present in the study’s population, therefore participants are currently exhibiting and living with asymptomatic kyphotic cervical spines. These research studies have highlighted that non-lordotic alignment is commonplace within a wide age range of asymptomatic research populations. The notion of a physiological cervical lordosis existing within us all has been compromised by the findings of these studies.
Kuntz IV et al. (2007) published a significant review paper related to asymptomatic sagittal spinal alignment and balance from the occiput to the pelvis. After correlating multiple angular and distance parameters, this research concluded that significant angular differences exist within all regional curves, often far outside +/- 2 SD. However, global spinal balance was maintained in the narrowest range of any parameter over the sacrum within the pelvic girdle. The authors stressed that most studies address either occipitocervical alignment or thoracolumbosacral alignment, failing to acknowledge the importance of craniopelvic alignment. The relevant literature is absolutely clear concerning sagittal alignment; its regional parameters are wide and global alignment is individualised (Vialle et al., 2005).

Normative data are vital as a reference point from which to draw comparisons while evaluating spinal balance from various planar perspectives (D. D. Harrison et al., 1996; McAviney, Schulz, Bock, Harrison, & Holland, 2005), therefore assessing what is theoretically normal is valuable. Coronal spinal alignment is well understood; if it is not straight, it is pathological (D. E. Harrison, Harrison, Troyanovich, et al., 2000; Roussouly et al., 2005). These researchers suggested although our knowledge base regarding sagittal spinal alignment has advanced, our understanding is still lacking in both adults and children. Sagittal spinal alignment and its relationship with individual vertebrae is exceedingly complex due to the individualised variability previously described. It can be defined by numerous means either inter-segmentally, regionally, or globally, irrespective of gravity (Vedantam, Lenke, Bridwell, Linville, & Blanke, 2000). Figure 2.2 signifies a diagrammatic representation of the proposed coronal alignment, and the variability in sagittal postural alignment resulting from the location of the head’s CoM (D. E. Harrison, Harrison, Troyanovich, et al., 2000).
Reviewing sagittal spinal balance in isolation is impractical without a basic knowledge concerning sagittal spinal alignment, as the two areas exist within an interdependent physiological framework. Authors frequently endeavour to describe spinal alignment variability and the deleterious consequences these altered spinal alignment parameters have on spinal balance and upright postural equilibrium. Researchers consistently conclude a unique and individual co-dependency exists between regional curves and their vertical orientation (Dolphens et al., 2012; Kuntz IV et al., 2007; Mac-Thiong et al., 2007; McAviney et al., 2005). Kuntz IV et al. (2007) reviewed studies with more than 150 participants to enhance validity and demonstrated no single study at the time of the review had appraised spinal parameters from the cranium to the pelvis. This craniopelvic relationship represents a linear chain linking the head to the pelvis, whereby one anatomical region’s alteration will refashion the neighbouring segments of the spine and/or pelvis.
Maintaining equilibrium to counter cranial variations is critical to facilitating the continuation of an erect posture that requires minimal energy expenditure to counter the force of gravity (Dolphens et al., 2012; Mac-Thiong et al., 2007; McAviney et al., 2005). The phrase “Regional Interdependence” was coined to describe how apparently unrelated MSK impairments in a distant anatomical region can cause the primary problem in another distinctly different region (Wainner, Whitman, Cleland, & Flynn, 2007). Regional interdependence perfectly denotes spinal alignment and the functional objective of spinal balance. Spinal balance is defined by a vertical plumb line dropped from a proximal point, with a horizontal line measured to a distal standardised point. The plumb line represents the sagittal vertical axis while the horizontal measurement allows intra- and inter-participant comparisons, and represents our best attempt at understand the effect gravity plays on alignment (Kuntz IV et al., 2007).

The conventional cranial location to commence a review into spinal balance and the sagittal vertical axis is the cranium’s CoM. A French research team in 1986 determined the cranium’s CoM by isolating the balance point within six suspended formolized heads, determining the CoM to lie within an area 1cm$^2$ anterosuperior to the attachment of the ear’s helix (Figure 2.3) (Vital & Senegas, 1986). Sugrue et al. (2013) redefined global spinal balance by performing a comprehensive investigation into the sagittal vertical axis within an asymptomatic sample of adults. Sugrue et al. (2013) used the identical cranial CoM location reported by Vital and Senegas (1986) providing support for this location representing the craniums true CoM.
Figure 2.3. Cranium’s center of mass. A. Location of the center of mass. B. Center of mass projections over an area approximately 1cm² in the region anterosuperior to the ear’s helix, adapted from (Vital & Senegas, 1986).

Experimentally, the cranial point at which the sagittal vertical axis is generated and projected caudally can vary from points other than the cranium’s CoM location. Kuntz IV et al. (2007) identified the tip of the odontoid process of C2, while other authors use the centre of C2 or C7 vertebral bodies as the proximal point to project the line of gravity distally (Gelb et al., 1995; Kobayashi, Atsuta, Matsuno, & Takeda, 2004; Park et al., 2013; Sugrue et al., 2013). The distal point at which the horizontal measure is generated is typically the posterior superior corner of the S1 end plate (Kobayashi et al., 2004; Park et al., 2013; Sugrue et al., 2013); however, Gelb et al. (1995) used the anterior inferior tip of the S1 endplate to determine the measure.
Figure 2.4. Radiograph demonstrating the cranium’s centre of mass. C2, and C7 plumb line projections reflecting the sagittal vertical axis, measured horizontally from the posterosuperior aspect of the S1 endplate, adapted from (Sugrue et al., 2013).
Kuntz IV et al. (2007) concluded that sagittal balance, reflected within the horizontal measures associated with the sagittal vertical axis, is restricted to a small alignment range over the pelvis and femoral heads. This review also indicated that the sagittal vertical axis translates anteriorly with age, resulting from the age-related increase in the cervical lordosis and the cranium’s overall anterior translation. The C2-S1 sagittal vertical axis varied from 73 mm anterior to 47 mm posterior of the plumb line, with an overall variation of 120mm. The C7–S1 sagittal vertical axis varied from 48 mm anteriorly to 48 mm posteriorly of the plumb line, with an overall variation of 96 mm (Figure 2.4) (Kuntz IV et al., 2007). These findings suggest the posterior limit of the sagittal vertical axis is no greater that 50mm from the posterosuperior corner of the S1 end plate, whereas the anterior limit is 73mm when determined from two different cranial points of origin being C2 and C7.

A large investigation was conducted by Mac-Thiong, Roussouly, Berthonnaud, and Guigui (2010) into the sagittal balance of asymptomatic participants aged between 18 to 81 years (n = 709). Their findings indicated that, while standing, a relatively stable global balance was adopted by asymptomatic adults. Their C7 sagittal vertical axis demonstrated a comparatively unchanging global balance due to the small range of measures representing mean +/- 2 SD. They also concluded no clinically significant differences were observable within the axis between males and females. Sugrue et al. (2013) investigated spinal parameters from the occiput to sacrum using long-cassette scoliosis radiographs (Figure 2.4). This research redefined global sagittal spinal alignment within two unrelated asymptomatic samples (n = 78, 20 to 40 years and n = 62, 60 to 80 years). Sagittal vertical axis measures were generated from three points being the cranium’s CoM, C2 and C7, allowing the researchers to conclude that, with advancing age, humans gradually translate anteriorly at all levels in a near linear correlation, further supporting the findings of Kuntz IV et al. (2007).
Gelb et al. (1995) reported within asymptomatic participants aged 40 to 82 ($n = 100$) that advancing age correlated positively with the anterior displacement of the sagittal vertical axis, which increased the loading parameters on the lumbar spine. Mac-Thiong et al. (2010) postulated anterior displacement of the C7 sagittal vertical axis cannot be attributed exclusively to the aging process, considering this alignment change to be borderline pathological. Their research was unable to indicate a significant correlation between advancing age and anterior displacement of the sagittal vertical axis with respect to sacrum, contradicting the review findings of Kuntz IV et al. (2007). Regardless of the findings, there is conjecture centred on normative sagittal vertical axis parameters and changes observed throughout the ages; however, methodological standardisation may contribute to a certain degree to the variability reported in the literature. It is evident that regional interdependence contributes to the considerable differences that exist within sagittal spinal alignment and global balance parameters between, and within, every spinal region.
2.5 Normal Cervical Anatomy: A Historical Perspective, Identification, Categorisation, Transitioning from Spinal Alignment and Balance Towards a Clinical Appreciation

A brief outline of normal cervical anatomy will establish a relevant theoretical framework capable of defining what are considered normal cervical spinal alignment parameters. The first large scale cervical curve evaluation was conducted by Borden, Rechtman, and Gershon-Cohen (1960) in an evenly mixed asymptomatic sample aged 21 to 80 ($n = 180$). Their findings indicated cervical curves exhibit range variability as large as C1 to T2, and while 164 (91.1%) participants exhibited a degree of lordotic alignment (Figure 2.5A), 13 (7.2%) exhibited a straight cervical alignment pattern and 3 (1.7%) exhibited a cervical kyphosis. Borden et al. (1960) intuitively considered, at this early stage of the cervical spines evaluative history, that straight cervical alignment patterns were abnormal if the cervical range of motion (ROM) was reduced, while a reversed cervical kyphotic curve was abnormal under any circumstance.

This consideration by Borden et al. (1960) indicates that researchers have, for a long time, been inquisitive regarding possible pathologies existing within asymptomatic participants exhibiting conformational cervical subtypes other than a cervical lordosis. Two years after the Borden et al. (1960) study, Juhl, Miller, and Roberts (1962) investigated and defined cervical spine variations in asymptomatic participants ($n = 116$). They identified 22 (19%) participants displaying straight cervical alignment patterns, 16 (13.8%) displaying a cervical kyphotic curve and 8 (6.9%) were shown to exhibit sigmoidal curves. Interestingly, this is the first mention within the literature regarding the cervical sigmoidal alignment pattern existing within a sample’s participants. An investigation conducted by D. R. Gore, Sepic, and Gardner (1986) on cervical alignment and degeneration has become a landmark paper within the cervical spine domain (cited 551 times to date).
Figure 2.5. Measurement of the cervical lordosis. A. Depth of curve measure for the cervical lordosis, adapted from (Borden et al., 1960). B. A cervical lordotic measure the Absolute Rotation Angle (ARA \( C_2-C_7 \)) (D. R. Gore et al., 1986), radiograph by Lee Daffin.

The D. R. Gore et al. (1986) sample consisted of asymptomatic participants \( (n = 200; 100 \text{ male,} 100 \text{ female}) \) aged 20 to 65, and the absolute rotation angle (ARA) (Figure 2.5B) was used to generate a descriptive measure able to indicate a standardised comparative lordotic angle. They were the first researchers to publish a normal cervical lordotic angle for the ARA \( C_2-C_7 \) being 23° from a large-scale study. This review also identified the younger age group, from 20 to 25, displayed the lowest mean angles, 16° for men and 15° for women, whereas the older age group from 60 to 65 displayed a greater mean angle of 22° and 25° for men and women respectively. The authors determined very little difference existed between male and female mean ARA \( C_2-C_7 \) angles throughout the decades; however, the overall mean ARA \( C_2-C_7 \) increased as participants aged. Kuntz IV et al. (2007) cited this study when they stated that the cervical lordosis increases with age. D. R. Gore et al. (1986) identified that 18 (9%) participants displayed cervical kyphotic angulations at a single disc space, either C4-5 or C5-6, ranging from 2° to 24°, with a mean of 4°. These alignment patterns were distributed across all age groups and related significantly to osseous degeneration.
Gay (1993) commented on the methodologies utilised by Borden et al. (1960), Juhl et al. (1962) and D. R. Gore et al. (1986), indicating the use of the ARA C2-C7 (Figure 2.5B) used by D. R. Gore et al. (1986) was not affected by magnification, generating greater reliability compared to the depth of curve measurement used by Borden et al. (1960) and Juhl et al. (1962). Gay (1993) was the first author to attempt descriptive standardisation of the cervical spine’s alignment qualities. He began by reviewing the relative literature concerning the clinical significance of cervical alignment. It was determined that if the anterior convexity was absent, the curve was referred to as a straight spine; if the convexity was posteriorly located, the curve was referred to as a cervical kyphosis. Gay (1993) expanded on the work of Juhl et al. (1962) describing extended motion segments (lordotic alignment) existing in conjunction with flexed motion segment(s) within a single alignment pattern, terming this a cervical angulation (sigmoidal). Gay (1993) radiographically described four curve variations being lordotic, straight, kyphotic and angulation (sigmoidal). Helliwell, Evans, and Wright (1994) defined the sigmoidal curve a year later as a “low straight” cervical curve.

D. D. Harrison et al. (1996) published an ideal theoretical model of the static sagittal cervical lordotic spine which evolved from their initial 1979 static circular geometric model. The authors enhanced the initial model by considering: mathematical modelling, biological tissue mechanics (loading and strain), static alignment, dynamic motion and structural design. The authors evaluated a mixed sample of asymptomatic participants with an average age of 35.4 years (n = 252). An exacting inclusion/exclusion criterion was applied to generate the lordotic measurements, and any gross loss of lordotic curve or kyphotic segmental angle was excluded. The authors also depicted and described the sigmoidal and reverse sigmoidal curves in which upper extended or flexed motion segments and lower flexed or extended motion segments were observed, respectively. For the first-time, descriptive standardisation for all curve classifications was evident in the literature.
D. D. Harrison et al. (1996) contrasted the radiographic lordotic measures against the predicted theoretical values demonstrating they correlated extremely well \((p = < 0.0001)\), producing an average error of only 5%. This study was a pivotal point during the historical evolution of angular measurements being used to report the sagittal cervical lordosis. The mean cervical lordotic ARA \(_{C2-C7}\) measurement was shown to be 34°, the male mean was 34.32° +/- 9.69°, while the female mean was 33.51° +/- 8.92°, and the range was 16.5° to 66°. The authors also generated several other measurements including the anterior translation of the head measure (ATHM) which was shown to be 15.5 mm. The atlas angle was shown to be 23.23° +/- 7.53° for males and 25.22° +/- 6.97° for females. An intersegment extension angle was generated for each vertebral pair, and termed the relative rotation angle (RRA). This angle proved to be very important when identifying intersegment kyphotic motion segments as is outlined in Chapter 5.

Gay (1993) concluded that a wide range of asymptomatic cervical curvatures have the capacity to be radiographically described, a finding strongly supported numerically by the D. D. Harrison et al. (1996) ARA \(_{C2-C7}\) data. Kuntz et al. (2007) presented their findings concerning the ARA \(_{C2-C7}\) parameter, concluding it ranged from 11° of kyphosis to 45° of lordosis, with a mean of 17° +/- 14° which proved to be the largest range of any spinal region’s parameter. At this point a consensus is clear within the literature that a cervical lordotic curvature represents the “physiological” or “normal” alignment situation for the cervical spine. Erkan, Yercan, Okcu, and Ozalp (2010) commented that no detailed normative cervical lordotic measure is evident within the literature due to the large range within the ARA \(_{C2-C7}\) parameter, an issue remaining problematic to this date and one which may remain problematic into the future.
2.6 Developing an Altered Cervical Alignment

It is clear within the literature considerable intra- and inter-individual variability is reported within all reviewed domains from sagittal spinal and cervical alignment, global and regional balance, cervical radiographic descriptors and measurements. Although the aforementioned parameters report large ranges, they are all accommodated over a narrow parameter at the pelvis, indicating the incredible ability the body retains to maintain equilibrium at any cost, even its own degeneration. To fully understand the development of altered cervical alignment, it is important to appreciate what the literature reveals about the proposed causative mechanisms and the intra- and inter-individual parameters used to classify this structural anomaly (C. S. Lee et al., 2012). D. R. Gore (2001) conducted a 10-year longitudinal investigation on his initial asymptomatic sample aged 20 to 65 ($n = 200$). He concluded, within the re-engaged sample ($n = 159$), the mean lordotic angle previously measured by the ARA$_{C2-C7}$ at 18° +/- 12.5° was now 19° +/- 11.9°, indicating the ARA$_{C2-C7}$ is a relatively stable parameter over a ten-year period. D. R. Gore (2001) also noted that 15% of participants developed neck pain and the severity of degenerative changes noted previously increase with age.
The loss of the cervical lordosis commonly observed radiographically has repeatedly been attributed to muscle spasm resulting in the different non-lordotic subtypes observed (Helliwell et al., 1994; Takeshima et al., 2002). The problem with this argument is that numerous studies report non-lordotic subtypes within their asymptomatic samples. Bearing in mind D. R. Gore (2001) indicated that the ARA$_{C2-C7}$ was a relatively stable parameter, it must be assumed that non-lordotic development has either a relatively slow transition phase, or, in the case of adolescents, the lordotic curvature failed to fully develop the individual’s ontogeny and therefore never existed in the first instance. These questions must be considered carefully when reviewing the literature to determine possible causation in this critical matter.

*Figure 2.6. Sagittal vertical axis (SVA). A. SVA Normal (N), without alterations to the global spinal balance. B. SVA forward head posture (FHP), with alterations to the global spinal balance, contrasting the anterior translated SVA FHP with the original located SVA N, adapted from (Darnell, 1983).*
A consequence of FHP is anterior translation of the sagittal vertical axis which detrimentally alters the equilibrium of the spines global sagittal balance (Figure 2.6). In 1983 the review “A proposed chronology of events for forward head posture” was published by Darnell (1983), who suggest two potential causative mechanisms. The first, representing prolonged and repetitive activities performed anterior to the trunk, over time may change the length/tension relationship within the cervical musculature. The second suggested that prolonged breathing with an open mouth may lower the mandibular position, resulting in a compensatory anterior translation of the occiput relative to the centre of gravity. The second mechanism could produce a similar length/tension effect in the cervical muscles. Regardless of which asymptomatic mechanisms are responsible, it is worth considering at this point that cervical non-lordotic subtypes are influenced to some extent by “Regional Interdependence”, whereby caudal MSK impairments are the impetus for the observed cervical alignment patterns.

Helliwell et al. (1994) investigated cervical alignment characteristics on radiographs (n = 232) obtained from two medical departments, radiographs drawn from patients with cervical symptomatology (n = 166) were compared with an age-matched control group aged between 16 to 87 years (n = 66). After reviewing the alignment characteristics and the symptomatic status of the participants, they concluded the loss of lordosis is not exclusively associated with muscle spasm caused by acute neck pain and cannot be automatically assumed when a loss of lordosis is evident. Importantly, they identified symptomatic participants with either acute or chronic neck pain (n = 111) exhibited a cervical lordotic alignment, while asymptomatic participants exhibited straight (n = 28) and kyphotic alignment (n = 23) subtypes. The author’s contest that most of the neck’s muscle mass is located posteriorly, and acute muscle spasm should result in cervical hyper-lordosis and not one of the non-lordotic alignment subtypes.
Takeshima et al. (2002) investigated variations in cervical flexion and extension kinematics in NSNP sufferers \((n = 204)\) with a mean age of 31.5 +/- 10.5, who all exhibited similar pain intensities. The authors categorised the participants into five groups: (1) lordotic, (2) straight, (3) kyphotic, (4) sigmoidal and (5) reverse sigmoidal, using a clearly described and depicted radiographic classification methodology (Figure 2.7). The authors agreed with Helliwell et al. (1994) that the mechanisms involved in the onset and maintenance of a straight, kyphosis, and/or S-shape cervical alignment are not the result of pain-generated muscular contraction. The authors indicated that the cervical lordosis can be maintained by participants who have NSNP that is of similar quality and intensity as the 4 alternative non-lordotic subtypes.

Figure 2.7. Radiographic cervical classification. Five groups are identified according to their cervical alignment subtype, adapted from (Takeshima et al., 2002).
C. S. Lee et al. (2012) investigated sagittal cervical alignment in asymptomatic children and adolescents aged 3 to 20 \((n = 181)\). They suggested this was the first study to radiographically detail standing cervical lordosis using the posterior tangent method \(\text{ARA}_{C2-C7}\) in asymptomatic children. This research group identified that the highest rate of cervical straight and kyphotic alignment \((n = 109, 60.2\%)\) occurred between the ages of 8 to 17, with 80 \((44.2\%)\) of the 109 participants exhibiting a cervical kyphotic alignment. The authors determined that increasing age correlated with a loss of the cervical lordotic curve until approximately 17 years of age, at which time the mean cervical lordotic measure increased marginally. Causation remains unclear as to why such an alarmingly large proportion \((n = 109, 60.2\%)\) demonstrated a loss of their cervical lordosis, and why there was a jump in the mean cervical lordotic measure between 18 to 20 years. It was suggested the small sample size of 20 participants within the 18 to 20-year range may have contributed to the jump in the mean cervical lordotic measure.

Yukawa, Kato, Suda, Yamagata, and Ueta (2012) investigated, among other measurement parameters, the cervical lordosis in an asymptomatic sample \((n = 1230)\). This study constituted at least 100 men and 100 women from every decade of life between the 3\(^{rd}\) and 8\(^{th}\) decades. Yukawa et al. (2012) determined females in their 3\(^{rd}\) (age 20 to 29) and 4\(^{th}\) (age 30 to 39) decades displayed 33.3\% and 27.5\% cervical kyphotic alignment measures respectively, whereas males in their 3\(^{rd}\) and 4\(^{th}\) decades displayed 19.4\% and 12.4\% respectively. The authors were surprised with the large number of kyphotic presentations within the younger decades and the large numbers observed within the female population. It is evident that asymptomatic non-lordotic alignment exists in large numbers within young populations (C. S. Lee et al., 2012; Yukawa et al., 2012) and is not the result of pain-generated muscular contraction (Darnell, 1983; Helliwell et al., 1994; Takeshima et al., 2002).
It is at this pivotal point regarding the development of the cervical non-lordotic alignment subtypes that one question must be asked: Why are non-lordotic alignment subtypes so prevalent and appearing to increase within our asymptomatic youth? To explore this question, we have to consider what has changed recently within this population that could credibly lend support to a possible answer. Children, adolescents and university students are increasingly exposed to sedentary lifestyles, mainly due to the rapidly growing exposure to screen-based activities on computers (Brink & Louw, 2013) and smartphones (Guan et al., 2016; Toh et al., 2017). Regardless of gender, clear evidence exists that these populations risk developing neck pain while using any form of modern electronic device whether sitting (Brink et al., 2014; Brink & Louw, 2013; Straker et al., 2011) or standing (Guan et al., 2016; Toh et al., 2017).

In the decade prior to the explosion of screen-based activities, Darnell (1983) suggested prolonged and repetitive activities performed anterior to the trunk may over time change the length/tension relationship within the cervical musculature resulting in FHP. Kang et al. (2012) reported that the average time spent on computer tasks from 1997 to 2003 increased from 5.9 to 14.6 hours per week. In a recent article, Fares, Fares, and Fares (2017) estimated that 75% of the world’s population spends hours on a daily basis with their head and neck flexed over their handheld devices. Fares et al.’s (2017) research indicated children and adolescents on average devote 5 and 7 hours a day, respectively, to interacting with their handheld devices assuming a sustained neck posture ranging anywhere between 30° and 60° of flexion (Figure 2.8). Alarmingly, this daily activity can be viewed as a cumulative average of 1825 and 2555 hours a year, respectively, of increased biomechanical stress placed on every tissue within the cranial aspect of the developing neuromusculoskeletal frame (Fares et al., 2017).
Figure 2.8. The stress and weight put on the neck and spine resulting from hunching over a smartphone and handheld devices at varying degrees. **A.** A full-grown head weighs 4.54 to 5.44 kg in the neutral position. **B.** The head weighs 18.14 kg at 30°. **C.** The head weighs 27.22 kg at 60°, adapted from (Fares et al., 2017).

C. S. Lee et al. (2012) agreed with Kang et al. (2012) stating that increased time assuming a habitually poor postural position when young appears to contribute to the development and perpetuation of the cervical kyphotic alignment subtype, vindicating Darnell’s (1983) early postulation. Yukawa et al. (2012) postulated that the younger population may be manifesting a generational change in the development and maintenance of the normal cervical lordotic alignment. Takeshima et al. (2002) commented that within our modern society, FHP is practically the universal head position observed. An enormous part of most individuals’ time is spent engaged in forward visual postures with their head protruded for activities including television and computer gazing, driving, reading and eating.
Kang et al. (2012), C. S. Lee et al. (2012), Yukawa et al. (2012) and Fares et al. (2017) all support the viewpoint that suggests modern society may be cultivating a generation that never developed a cervical lordosis to begin with, resulting from an interaction and obsession with modern technology. Fares et al. (2017) suggested the effects of non-lordotic alignment transcend neck pain, and influence multiple aspects within an individual’s biopsychosocial outlook on health. It is feared that biomechanical stress may lead to early degeneration and associated complications within the visceral organs of the thoracic cavity, potentially reducing the life expectancy within the current younger population (Fares et al., 2017).

An overview of the literature related to the development of non-lordotic alignment subtypes leans towards a slowly adapting asymptomatic alteration in the cervical alignment pattern brought about by the significant time spent involved in screen-based activities within the youth. This detrimental alignment alteration can either develop from a previously existing cervical lordosis or develop independently as non-lordotic cervical spine; the latter appears now to have greater support within the literature.
2.7 Spinal Degeneration, Coinciding with Altered Cervical Alignment and Aging

Yukawa et al. (2012) indicated that most cervical radiographic parameters exhibit gradual progressive degeneration through the decades. Marchiori, Brozovich, Adams, and Duffy (1997) reported the most common and reliable cervical radiological degenerative signs are anterior osteophyte formation, disc space narrowing, facet and end plate sclerosis and uncinate hypertrophy. Yukawa et al. (2012) identified the vertebral end plate intervertebral disc (IVD) interface as the region where degeneration in the cervical spine was more prevalent, when compared to the mid vertebral regions. Matsumoto et al. (2010) investigated the cervical spine through magnetic resonance imaging, concluding the cervical spine exhibited considerably more marked degenerative signs than the thoracic spine through the decades. Okada et al. (2009) undertook a comprehensive 10-year longitudinal magnetic resonance image (MRI) investigation into cervical spine aging in an asymptomatic sample aged 11 to 71 years \( (n = 223) \), concluding that participants under 50 years have a greater prevalence to display soft tissue (IVD) degeneration while participants over 50 are more likely to display osseous (foraminal stenosis) degeneration, supporting the findings of Yukawa et al. (2012) and Matsumoto et al. (2010).
A number of disturbing findings resulted from E. Okada et al.’s (2009) study, with 84.8% of the participants displaying progressive IVD degeneration, with C5-6 the highest level, preceded by C6–C7, C4–C5, C2–C3, and C7–T1. Soft tissue and osseous degeneration were present in 17% of the males and 12% of the females now in their 3rd decade (who were teenagers 10 years earlier), while, 86% of the males and 89% of the females over 60 displayed cervical degenerative changes. Neck and shoulder pain developed in 34.1% of the cohort over the proceeding decade; however, the symptomatic age distribution was not reported. Clinical symptomatology correlated significantly with larger levels of degeneration when compared with asymptomatic participants (E. Okada et al., 2009).

E. Okada et al. (2009) re-evaluated their longitudinal data to investigate whether an association between progressive IVD degeneration (Figure 2.9) and sagittal cervical alignment existed. They concluded that male non-lordotic participants over 40 displayed significantly more degeneration; however, no significant correlation was observed between sagittal curvature and symptomatology. They further commented that non-lordotic alignment impacted the progressive degenerative changes associated with aging, a finding supported by these three research groups D. R. Gore et al. (1986), Ames et al. (2013) and Nouri et al. (2015). Gellhorn, Katz, and Suri (2013) remarked that osseous degenerative changes display only a weak association with clinical symptomatology, a view supported by E. Okada et al. (2009). Osseous degeneration has a strong predilection for the human cervical spine, no age group is immune, and evidence suggests non-lordotic alignment may augment this disease (Okada et al., 2009).
Figure 2.9. Cervical MRI and radiographic case presentation. A. Sagittal cervical spine MRI image obtained at the original study of a 37-year-old male with no clinical symptoms at the time. B. Twelve years later, 49-year-old male demonstrated progression of the posterior intervertebral disc protrusion at C5/6 and now also at C4/5 and C6/7. C. Sagittal plain film radiograph of the 37-year-old male who still remained free of clinical symptoms related to the cervical spine at 49 years of age, adapted from (E. Okada et al., 2009).
2.8 Cervical Alignment and Pain Syndromes

Chronic MSK pain is common amongst adolescents and adults (McBeth & Jones, 2007). Pain is always a subjective phenomenon open to the interpretation of the individual. At its most rudimentary level, pain is an unpleasant sensory and emotional occurrence, accompanying actual or potential tissue damage (Bonica, 1979). From the viewpoint of a neurobiologist, the perceptual phenomenon of “pain” is experienced in three quite different ways. Firstly, there is high-threshold nociceptive pain, which fundamentally serves as a biological protective system that detects noxious stimuli (hot, cold, sharp) and endeavours to minimise physical contact with the stimuli. It demands immediate action to maintain bodily integrity. Secondly, there is inflammatory pain, both adaptive and protective. Following tissue damage (neck structures), inflammation intensifies sensory sensitivity to suppress the desire for physical contact and movement which promotes recovery. Thirdly, somatic and visceral structures have the capacity to negatively influence the central nervous system. Permanent maladaptive neuroplastic changes are elicited through abnormal function, damage and disease. Pathological pain is the collectively termed representing this non-protective, detrimental, long-term disease state. (C. J. Woolf, 2010).
Asymptomatic individuals’ transition into NSNP sufferers, therefore the importance of understanding what the literature indicates concerning pain (symptomatology) and its association with cervical alignment is critical. The precise nature of the pathways and mechanisms of association related to the transition from an asymptomatic individual into NSNP sufferers in childhood, adolescence or in adulthood are unclear and necessitate additional rigorous investigation (Fares et al., 2017; McBeth & Jones, 2007). The enormity of this problem was brought to light recently when Fares et al. (2017) investigated MSK neck pain, determining 180 (87%) of the children and adolescents exhibited clinical signs of NSNP ($n = 207$). The concern is at one stage all these participants were asymptomatic and they have now all transitioned into NSNP sufferers.

D. R. Gore et al. (1986) postulated a link between neck pathology and the loss of the normal cervical lordosis, whereas twelve years later G. M. Johnson (1998) suggested that prolonged FHP might increase the loading on the neck’s holding elements, straining the posterior cervical musculature and allowing myofascial pain syndromes to perpetuate. Lau-Tung et al. (2010) indicated the greater the degree of FHP a participant presented with, the more prone they were to exhibit neck pain. Griegel-Morris, Larson, Mueller-Klaus, and Oatis (1992) conducted a very early investigation into the effects of poor upper body posture in an asymptomatic sample (at the time of testing) aged 20 to 50 ($n = 88$). These researchers postulated poor posture should be cumulative, with more severity in postural variations witnessed after 35 years of age. However, results indicated most of the cohort displayed visual postural abnormalities in their upper body, FHP (66%), hyper-kyphosis (38%), rounded shoulder right (73%) and left (66%).
All eligible participants completed a pain questionnaire to both qualitatively and quantitatively evaluate their past neck and shoulder pain experiences. Griegel-Morris et al. (1992) identified an increased incidence of cervical pain, upper thoracic pain and headaches associated with forward head posture, concluding that pain is more likely to be experienced in participants with severe postural abnormalities when compared to less severe and normal postures. However, a relationship between the severity of neck pain and the degree of postural abnormalities was not established. D. R. Gore (2001) evaluated 159 of the original 200 participants from his 1986 study to determine how many participants developed neck pain, and if an association exists between symptomatology and radiological findings. Participants developed neck pain within the first year, and up to 10 years after the conclusion of the initial study. The mean onset was 4.9 years.

D. R. Gore (2001) indicated 15% of the cohort became symptomatic at the mean age of 48.1 years. Siivola et al. (2004) reported at the conclusion of their seven-year longitudinal study that weekly NSNP increased from 15 to 30% in a sample of young adults (n = 826), initially aged 15 to 18 and now 22 to 25. Okada et al. (2009) indicated that over 10 years, 34% of the previously asymptomatic sample aged 39 +/- 15 (n = 223) developed NSNP. It is evident from the findings of D. R. Gore (2001), Siivola et al. (2004) and Okada et al. (2009) that a certain percentage of previously asymptomatic participants developed NSNP over time. If we combine the results from these three studies, we find a mean value of 26% developed NSNP, representing one in four participants.
D. D. Harrison et al. (2004) reviewed radiographic measurements from 72 asymptomatic, 52 acute pain and 70 chronic pain participants, with a mean age of 39. The mean ARA \( C_2-C_7 \) data for the asymptomatic participants was 34.5°, acute pain 28.6° and chronic pain 22°. Two additional radiographic parameters including the ATHM were 3.9mm, 15.2mm and 14.8mm, respectively and, the atlas angle was 28.8°, 20.1° and 18.9°, respectively. The authors concluded pain participants typically exhibit non-lordotic alignment, greater anterior head translation (FHP) and a reduced atlas angle when compared to asymptomatic participants.

McAviney et al. (2005) conducted a retrospective investigation into cervical alignment and its relationship to neck pain. The study investigated 227 outpatient files of participants aged 9 to 78 (mean of 38). The ARA \( C_2-C_7 \) was used to determine the cervical (alignment) angle as the ARA \( C_2-C_7 \) demonstrates high intra- and inter-examiner reliability when compared to the Cobb Method (D. E. Harrison, Harrison, Cailliet, et al., 2000). The authors concluded the majority of participants with ARA \( C_2-C_7 \) of 20° or less reported cervical pain; an ARA \( C_2-C_7 \) between 20° to 30° was relatively similar in relation to cervical pain and non-cervical pain participants. The majority of non-cervical pain participants displayed ARA \( C_2-C_7 \) of 31° to 40° and most of the participants displayed cervical pain if the ARA \( C_2-C_7 \) was greater than 40°. They identified an ARA \( C_2-C_7 \) of 31° to 40° to be the clinically (functional) normal ARA \( C_2-C_7 \) angle, supporting the 34° ARA \( C_2-C_7 \) modelled by D. D. Harrison et al. (1996). The authors established that only 4% of the cervical straight and kyphotic subtypes were asymptomatic, and these non-lordotic subtypes were 18 times more likely to exhibit NSNP.
Yip, Chiu, and Poon (2008) investigated the relationship between head posture and neck pain in a sample consisting of asymptomatic ($n = 52$) and symptomatic ($n = 62$) participants with a mean age of 39.92 +/− 10.8. They concluded participants with neck symptomatology commonly present with a significant forward head posture, represented by a significantly smaller craniovertebral angle (CVA) (Figure 2.10) (mean 49.93 +/− 6.08) when contrasted against the asymptomatic participants CVA (mean 55.02 +/− 2.86). The authors claimed that their research results were the first to identify a relationship between FHP and the degree of neck pain severity and disability. The older the neck pain participant, the smaller the CVA and the higher the pain scale score, and vice versa. Fernandez-de-las-Penas, Alonso-Blanco, Cuadrado, and Pareja (2006) investigated FHP in a sample consisting of chronic tension-type headache sufferers age 20 to 70 (mean 42 ± 18) ($n = 25$) and asymptomatic participants aged 22 to 70 (mean 40 ± 12) ($n = 25$). These researchers concluded that participants with chronic tension-type headaches exhibited a smaller CVA ($45.3^\circ ± 7.6^\circ$) and greater FHP compared to the asymptomatic samples with larger CVA ($54.1^\circ ± 6.3^\circ$).

*Figure 2.10. Craniovertebral angle (CVA) a sagittal photogrammetric measure. A. A smaller craniovertebral angle. B. A larger craniovertebral angle, photographs by Lee Daffin.*
Fernandez-de-las-Penas, Alonso-Blanco, Cuadrado, Gerwin, and Pareja (2006) also investigated FHP and its quantitative relationship with chronic tension-type headaches and trigger points concluding a greater FHP (CVA) correlates positively with increased headache duration and frequency, and active suboccipital trigger points. These findings indicate that FHP places undue biomechanical stressors on the posterior holding elements of the craniovertebral region, perpetuating neuromusculoskeletal dysfunction. Silva, Punt, Sharples, Vilas-Boas, and Johnson (2009a) investigated the CVA between NSNP participants aged 33 to 69 (mean 50.2 ± 7.9) (n = 40) and asymptomatic participants aged 34 to 68 (mean 50.2 ± 7.9) (n = 40). Silva et al. (2009a) concluded NSNP participants exhibited a significantly smaller CVA (45.4° ± 6.8°) resulting in greater FHP than the asymptomatic participants (48.6° ± 7.1°).

Silva et al. (2009a) suggested these findings may be too small to be clinically meaningful, therefore the sample was divided into young (≤ than 50 years) and old (> than 50 years) populations. Silva et al. (2009a) uncovered a very interesting interaction; significance was shown in the young population’s CVA, NSNP participants 46.1° ± 6.7° exhibited greater FHP compared and asymptomatic participants 51.8° ± 5.9°, while no significance was shown in the old population’s CVA, 44.8° ± 7.1° and 45.1° ± 6.7°, respectively. The mechanisms of association within the older population are unclear; however, a factor of age-related cervical degeneration would impact the structural integrity of this region and would be highly suggestive as the possible causative agent across this population. To conclude this section on cervical alignment and pain syndromes, the words of D. D. Harrison et al. (2004) are pertinent, “These findings of reduced cervical lordosis in neck pain patients give credence to clinicians and researchers who seek to describe neck pain in mechanical terms”.

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D. D. Harrison et al. (2004) went further and suggested that palliative relief of symptoms should not be the sole sought-after clinical outcome. The cervical lordosis is positively correlated to an individual’s wellbeing and functional capacity; its restoration is an appropriate clinical outcome. Together with D. D. Harrison et al.’s (2004) findings, the reviewed studies of McAviney et al. (2005), Yip et al. (2008) and Silva et al. (2009a) have all tentatively suggested that altered cervical curvatures constituting non-lordotic alignments are to some extent correlated with clinical symptomatology. These authors findings potentially indicate a mechanistic inter-relationship may exist between non-lordotic subtypes and neck, head and shoulder pain. The literature concerning this issue is limited therefore, caution must be taken when inferring anything but a weak association between cervical alignment and pain. Asymptomatic individuals with non-lordotic subtypes transition into NSNP sufferers; however, several asymptomatic-to-NSNP transitional mechanisms of association remain unknown, including the neurological mechanisms. We are at a critical point in this review. There is a clear mechanistic transition mechanism; however, what does the literature indicate about the nervous system’s role in transition?
2.9 The Cervical Spine’s Relationship with the Nervous System

The nervous system is complex. A logical point to begin a review into the association between cervical alignment and the nervous system was determined to be proprioception. It is from the understanding of this neural mechanism that this review will expand and continue to explore the relationships between cervical alignment and the various neural mechanisms responsible for regulating functional and/or dysfunctional body control. Hillier, Immink, and Thewlis (2015) discuss the concept of proprioception in its simplest form is having the ability to “perceiving one’s own self” in terms of body orientation, position and motion. Proprioception is a key component of the somatosensory system, along with pain, touch, and thermal sensation, and is deemed to be interoceptive as transformations within internal structures are the impetus for the afferent input.

de Vries et al. (2015) and Hillier et al. (2015) both conducted comprehensive systematic overviews on the literature relating to cervical proprioception. Both reviews indicated that muscle spindles are the dominant proprioceptive receptor responsible for providing afferent input and receiving efferent output from the central nervous system (CNS). These specialised receptors are located within each muscle and have the capacity to perceive a change in muscle length and the rate of the change in length (Figure 2.11). Muscle spindles exist in high densities within the cervical spine, in particular the suboccipital region (Kulkarni, Chandy, & Babu, 2001; Liu, Thornell, & Pedrosa-Domellöf, 2003) where numbers can reach approximately 200 muscle spindles per gram of muscle mass (Treleaven, 2008). Treleaven (2008) considered this density extremely high when compared to the thumb’s first lumbricals which possesses approximately 16 muscle spindles per gram of muscle mass. Hillier et al. (2015) states proprioception is not the sole domain of the muscle spindle; many
alternative receptors provide additional information concerning joint position and motion sense.

Figure 2.11. Line diagram of the multifidus and longus colli (LC) in situ depicting their bilateral arrangement adjacent to a lower cervical vertebra (C5–C7). Depicted in the resected figures are circles representing the distribution of each spindle within that muscle. The black region within the M and LC muscles illustrates the highest spindle distributions while, white region illustrates the least spindle distribution for each muscle, adapted from (Boyd-Clark, Briggs, & Galea, 2002).

These alternative receptors have considerable specificity and sensitivity, and include free nerve endings, cutaneous receptors, Ruffini endings, Pacinian corpuscles, capsular receptors and Golgi tendon organs, being located ubiquitously within the human form (de Vries et al., 2015; Hillier et al., 2015). Stimulation of the various mechanical receptors can vary considerably from either a lower or higher mechanical threshold, while adaption of the
receptor to the stimuli may occur slowly or exceedingly more quickly. These receptors permit accurate determination of many significant variables the body must regulate in order to function appropriately from static joint position, intra-articular pressure, limb acceleration and deceleration (Hillier et al., 2015). The sensorimotor system not only incorporates afferent (somatosensory) information, it also comprises efferent output and central integration involving the complex coordination and processing of neural input and output. Functional sensorimotor control is governed by constant afferent input to the diverse levels within the CNS, then upon integration, efferent output effects the desired changes to maintain system equilibrium (Michiels et al., 2013).

Sensorimotor control provides the neural integrity necessary to sustain functional joint stability across the skeletal system, therefore this system is primarily responsible for the stability required within a functional cervical spine (Michiels et al., 2013). Cervical spine proprioceptive input is a critical factor in maintaining cervical functionality. This significance is reflected in the vast number of mechanoreceptors within this region, and, in particular, the suboccipital muscles (Treleaven, 2008). Cervical proprioceptive input converges with the vestibular nuclei, the visual system and several additional CNS areas (Michiels et al., 2013; Treleaven, 2008). These central and reflex connections with the vestibular and visual systems are vital for sensing motion and spatial orientation from both visual and gravitational stimuli. Accurate head-on-trunk movement-related orientation and coordination is unattainable without health sensorimotor integration (de Vries et al., 2015; Hillier et al., 2015; Michiels et al., 2013; Treleaven, 2008).
Standing in a stable upright posture is considered one of the most rudimentary postural control requirements to successfully interact with the external environment; it is dependent on functional CNS integration (Hillier et al., 2015; Treleaven, 2008). Malmström, Karlberg, Fransson, Lindbladh, and Magnusson (2009) indicated the cervical spine’s proprioceptive input is important for functional head-on-trunk coordination. This research was able to demonstrate that precise head-on-trunk orientation was achievable without vestibular input. It is clear the significance proprioception plays in the overall neural integration mechanism required by the human body to effectively accomplish environment homeostasis. The literature has determined that functional proprioception is fundamental to a healthy life, therefore a point has been reached whereby we need to explore the literature to determine the association between the cervical spine and dysfunctional proprioception. Proprioceptive impairment is assumed to positively influence persistent pain (Harvie et al., 2016).

M. Y. Lee, Lee, and Yong (2014) investigated FHP and its relationship with proprioceptive accuracy through joint position sense (JPS) testing within participants with FHP (CVA $\leq 53^\circ$) ($n = 19$) and asymptomatic participants with no FHP (CVA $>53^\circ$) ($n = 20$) with a mean age of 22.5. M. Y. Lee et al. (2014) concluded that FHP is associated with impaired proprioception, possibly resulting from a structurally induced change in the muscle length due to prolonged FHP, while a positive correlation was found between impairment and the increasing degree of FHP. Yong, Lee, and Lee (2016) investigated head posture and its correlation with proprioceptive function through JPS testing within asymptomatic participants (CVA $53.7 \pm 5.1$) with a mean age of 22.3 ($n = 72$, 35 males and 37 females). Testing involved head repositioning into flexion and extension measured by a digital inclinometer. Yong et al. (2016) identified a significant negative correlation between the
CVA and JPS errors in both flexion and extension, indicating asymptomatic participants with FHP possess impaired proprioception, possibly from reduced muscle length and altered muscle spindle activity.

The research conducted by Yamauchi et al. (2017) examined suboccipital muscles morphologically in an effort to establish the function role of this muscle group (Figure 2.12). Yamauchi et al. (2017) determined 86.4% of the sampled rectus capitis posterior major muscles (RCPma) and rectus capitis posterior minor (RCPmi) muscles exhibited a normal muscular appearance, while 13.6% had an abnormal morphology. The morphological appearance of both the obliquus capitis superior (OCS) or obliquus capitis inferior (OCI) in all 25 cadaver specimens was normal. Yamauchi et al. (2017) suggested the cross-sectional area of the RCPmi and OCS indicates a greater capacity to generate force in relation to the RCPma and OCI, thus implicating their role as anti-gravitational in nature. Significantly, Yamauchi et al. (2017) proposed that sustained head extension, as observed in FHP, may, in individuals with abnormal suboccipital muscles, perpetuate dysfunction resulting from biomechanical stress.
de Vries et al. (2015) published a comprehensive systematic review on the literature concerning the effect traumatic neck pain and NSNP have on JPS and proprioceptive impairment compared with asymptomatic participants. de Vries et al. (2015) included 14 studies within their review, concluding their findings were ambiguous in relation to JPS impairment within the three populations across all studies; however, JPS impairment was significantly demonstrated in both neck pain groups if six or more trials were performed. One year later, Stanton, Leake, Chalmers, and Moseley (2016) published a systematic review and meta-analysis that critically appraised the existing literature regarding proprioceptive impairment within chronic NSNP sufferers by investigating their JPS and that of asymptomatic participants. Stanton et al. (2016) included 13 studies with a pooled participant population of NSNP sufferers ($n = 587$) and asymptomatic participants ($n = 301$) that all performed cervical JPS testing.
Stanton et al. (2016) reported participants with chronic NSNP have moderately impaired cervical JPS compared with asymptomatic participants when undertaking head-to-neutral repositioning tests. These two reviews into neck pain and proprioceptive impairment through the use of JPS testing imply neck pain, whether traumatic or nonspecific, demonstrates overall higher JPS impairment than in asymptomatic participants, reflecting aberrant afferent input from the cervical spine (de Vries et al., 2015; Stanton et al., 2016). As functional head-on-trunk movement takes place, cervical muscles relay afferent information to the vestibular nuclei.

Currently visual and vestibular systems information regarding the head-on-trunk movement is also converging on the vestibular nuclei. This converging afferent information elicits three reflexes, being the cervico-ocular reflex (COR), vestibulo-ocular reflex (VOR) and the optokinetic reflex (OKR), to avert retinal image slippage resulting from head-on-trunk movement (de Vries et al., 2016). de Vries et al. (2016) investigated proprioceptive impairment in the COR. This ocular stabilisation reflex is generated to stabilise the eyes in response to rotation of the neck and/or trunk-to-head movements. Afferent spindle input from the neck’s deep muscles and facet joints trigger this objective, non-voluntary COR which functions in precise unity with the VOR.

Vestibulum input triggers the VOR to stabilise the eyes during head motion, and it is experimentally assumed this reflex is independent and unaltered by the COR. de Vries et al. (2016) reported the COR in NSNP sufferers exhibits hyperreflexia in comparison to asymptomatic participants, while in both groups the VOR remained unchanged and similar. It was concluded that possible aberrant afferents from the cervical spine of NSNP sufferers were responsible for the observed hyperreflexia. Preserving clear vision during head and eye
movements requires precise coordination between these reflexes, and this study suggests the VOR does not compensate for the COR hyperreflexia in NSNP sufferers. Incompatibility between these reflexes could result in decreased postural control, dizziness, and visual disturbances (de Vries et al., 2016).

Harvie et al. (2016) investigated proprioceptive precision during head rotation within a virtual domain. The sample consisted of 24 mild to moderate neck pain participants with a mixed etiology (mean age 44 ± 15), and 24 age and sex-matched asymptomatic participants. These researchers identified that asymptomatic participants could distinguish with a greater degree of accuracy differences between virtual and true head rotation when compared to neck pain sufferers. Harvie et al. (2016) concluded proprioceptive precision related to neck motion appeared inferior within neck pain sufferers and the level of impairment correlated positively with perceived pain severity.

Sa and Silva (2017) investigated cervical proprioception, pain sensitivity, anxiety and catastrophizing within NSNP sufferers (n = 40) and asymptomatic participants (n = 40) with a mean age of 17.2 ± 0.56 years. The authors determined NSNP sufferers demonstrate higher levels of anxiety and catastrophizing, lower pressure pain thresholds and higher JPS impairment during head repositioning tasks than asymptomatic participants, suggesting aberrant cervical proprioceptive impairment and maladaptive higher order processing is exhibited in adolescent NSNP sufferers. It is evident from the literature that the cervical spine has a complex functional inter-relationship with the CNS, indicating that afferent proprioceptive input from several specialised neck receptors are critical for normal functionality. de Zoete, Osmotherly, Rivett, Farrell, and Snodgrass (2017) believe their systematic review and meta-analyses to be the first-ever quantitative review to examine
whether sensorimotor JPS testing can identify, then quantify, differences between NSNP sufferers and asymptomatic participants. The de Zoete et al. (2017) review included studies \((n = 23)\) with sample sizes ranging from 7 to 91 individuals, and concluded JPS testing demonstrates a significant difference between idiopathic neck pain and healthy groups.

Recent evidence suggests asymptomatic alterations in cervical alignment (FHP) result in a reduction in the length of the cervical musculature, ultimately affecting muscle spindle activity and contributing to impaired proprioception and JPS errors. The literature is clear, regardless of the etiology, neck pain sufferers exhibit aberrant afferent input (proprioceptive impairment) when compared to asymptomatic participants. Interpreting the relevant data related to measuring proprioception indicates a capacity to do so through several different testing protocols including JPS testing, the cervico-ocular reflex and visualisation within the virtual domain. Regardless of the testing protocol, it was shown that neck pain sufferers exhibit proprioceptive impairment, and proprioceptive impairment is now believed to perpetuate chronic neck pain, which then influences many negative aspects of the biopsychosocial model of health.
2.10 Cervical Alignment, Sensorimotor Integration, Neck Pain and Postural Control

During this literature review several closely associated domains related to the cervical spine have been investigated, allowing the sequential development in knowledge required to answer the primary research question. The reviewed literature permits a critical appraisal of the associations between the mechanistic cervical spine, sensorimotor integration, neck pain and postural control, while undertaking the most fundamental of human processes, upright stance. Effective functional postural control while standing upright requires the precise integration of information from the somatosensory, vestibular and visual systems. As integration occurs, the CNS prepares and implements the appropriate efferent response required to successfully maintain upright stance (Abrahamova & Hlavacka, 2008; Hillier et al., 2015; Treleaven, 2008; Zultowski & Aruin, 2008).

Postural sway perpetuates itself; it is a direct manifestation resulting from the implemented postural control strategies necessary to preserve the body’s CoM within the body’s base of support. Minimising postural sway parameters while maintaining upright stance is the primary objective of functional postural control (Ruhe et al., 2011; Silva & Cruz, 2013; Yamamoto et al., 2015). Throughout the stochastic oscillations that constitute postural sway, the body’s CoM is projected towards the stance surface, generating a ground reaction force which is termed the CoP (Zultowski & Aruin, 2008). Functional postural sway is accurately controlled through rapid CoP changes that just surpass the present position and trajectory of the CoM to accelerate the CoM in the reverse direction of its current position, in order to maintain the CoM over either a static or dynamic base of support (BoS) and achieve postural control (Baratto, Morasso, Re, & Spada, 2002; Ruhe et al., 2011; Yamamoto et al., 2015).
Postural sway is measurable, this time criterion is routinely assessed by conducting stance trials on a force-platform. Quantification of this measure is achieved by recording the CoP oscillation profile generated by the body’s CoM postural sway ground reaction force (Yamamoto et al., 2015; Zultowski & Aruin, 2008). Force-platform generated CoP parameters are the gold standard when assessing postural control, with minimal excursion between the CoM and the BoS indicating greater postural control and superior neurological coordination (Crétual, 2015; Paillard & Noe, 2015; Roijezon, Clark, & Treleaven, 2015; Silva & Johnson, 2013). The literature relating to the domain of postural control (posturographic measurement) is vast; this review focuses on literature related to the cervical spine and the associated effects symptomatic neck pain has on postural sway parameters within populations ranging from adolescents to the elderly. Technical and methodological literature is introduced in the following chapters where its relevance is more applicable. The current literature is presented sequentially, initially focusing on single studies related to age-related changes, followed by NSNP, then concluding with the two published systematic reviews within this domain.

As this literature is introduced, it is important to appreciate the poignant comments two key researchers in the cervical spine, neck pain and postural control domain have conveyed. Ruhe et al. (2011) and Silva and Cruz (2013) agree that the heterogeneous nature of the studies’ methodologies make inter-study comparison very difficult, and in general the experimental setup and documentation is poorly executed. As part of Finland’s nationwide Health 2000 examination survey it was decided normative postural control parameters should be determined within a large representative sample. Era et al. (2006) investigated postural control in participants representing a normal cross section of the population age 30 to 90 years (n = 7979), concluding that postural control significantly decreases with age.
Era et al. (2006) demonstrated within participants aged 30 to 39 a significant spike in decreased postural control, followed by a progressive steady decrease to 60 years of age, then a rapid acceleration in decreased postural control once 60 was surpassed. Abrahamova and Hlavacka (2008) investigated postural control in asymptomatic participants age 20 to 82 (mean age 46.93) \((n = 81)\), segregating the sample into three groups: juniors aged 20 to 40 (mean age 24.8) \((n = 34)\), middle aged 40 to 60 (mean age 52.5) \((n = 20)\) and seniors aged 60 to 82 (mean age 70.7) \((n = 27)\). Abrahamova and Hlavacka (2008) determined postural control parameters demonstrated an ability to distinguish juniors from seniors, and middle-aged from seniors in all tasks. They concluded that it is apparent that postural control decreases from approximately the age of 30, and after 30, postural control progressively decreases throughout life until the age of 60 where it rapidly decreases. Abrahamova and Hlavacka (2008) agreed with Era et al. (2006) that postural control significantly decreased at approximately the age of 60.

Ekdahl, Jarnlo, and Andersson (1989) investigated postural control in asymptomatic participants (74 men and 78 women) age 20 to 64 \((n = 152)\), concluding older participants exhibited significantly decreased postural control compared with younger participants. The Ekdahl et al. (1989) findings demonstrated females exhibit increased postural control parameters across all age groups when related to age-matched males. Abrahamova and Hlavacka (2008) came to the same conclusion as Ekdahl et al. (1989), that females exhibit increased postural control parameters across all age groups. As this review finalises its appraisal of the effect aging has on postural control, it focuses on NSNP and the effect non-traumatic neck pain has on postural control parameters through a review of 10 key studies published in this domain between 1997 and 2012. Following this review, a compendium of the key findings related to NSNP and postural control is presented. Reviewing, in detail,
traumatic neck pain and its effect on postural control parameters is beyond the scope of this review.

McPartland, Brodeur, and Hallgren (1997) investigated postural control and suboccipital muscle atrophy in participants with chronic NSNP ($n = 7$) and asymptomatic participants with a mean age of 39.2 ($n = 7$), concluding that participants with chronic NSNP exhibited decreased postural control in comparison to the asymptomatic participants. McPartland et al. (1997) identified within the MRI images that the suboccipital muscles were normal in asymptomatic participants while the chronic NSNP participants exhibited fat tissue infiltrated bilateral atrophied RCPma and ($\leq 50\%$) RCPmi. McPartland et al. (1997) suggest that a reduction and impairment in suboccipital proprioception could account for the decreased postural control in NSNP sufferers. Michaelson et al. (2003) investigated postural control in participants with chronic NSNP ($n = 9$), with WAD ($n = 9$) and asymptomatic participants ($n = 9$), with a mean age of 41.7, concluding that significantly decreased postural control was evident in WAD participants whereas nonsignificant differences were observed in NSNP participants compared to asymptomatic participants. Michaelson et al. (2003) contribute the findings to the etiology of the neck pain.

Madeleine, Prietzel, Svarrer, and Arendt-Nielsen (2004) investigated postural control in participants with WAD ($n = 11$) and asymptomatic participants ($n = 11$) with a mean age of 33.2. Asymptomatic participants, once tested, received a hypertonic saline (6%) injection into the right trapezius, 2cm lateral to C7 to induce NSNP. Madeleine et al. (2004) concluded participants with WAD exhibited decreased postural control in comparison to the asymptomatic participants; however, NSNP induced asymptomatic participants exhibited no significant difference in postural control parameters. Madeleine et al. (2004) indicated
impaired proprioception was potentially responsible for the decreased postural control observed in WAD participants, and induced NSNP was of low intensity and too localised, therefore afferent muscle spindle sensitivity was not reduced enough to sufficiently decrease postural control in the asymptomatic participants.

Field, Treleaven, and Jull (2008) investigated postural control in participants with NSNP \((n = 30)\), with WAD \((n = 30)\) and asymptomatic participants \((n = 30)\) with a mean age of 28.3. Field et al. (2008) conducted this investigation to determine whether decreased postural control was greater in neck pain generated by trauma (WAD) in comparison to NSNP or non-trauma origin. It was concluded the research assumptions were correct; significantly decreased postural control was observed in both neck pain groups, with WAD participants exhibiting the greatest deficits in postural control when compared to asymptomatic participants. The findings suggest participants with WAD and NSNP may use different postural control strategies due to the etiology of the neck pain; however, altered afferent input is perhaps the primary cause of the decreased postural control observed in both groups.

Poole, Treleaven, and Jull (2008) investigated postural control and gait speed in female participants with NSNP \((n = 20)\) and asymptomatic participants \((n = 20)\) with a mean age of 70.9, demonstrating significantly decreased postural control within the elderly group with NSNP compared to asymptomatic participants. The authors suggested neck pain may contribute to the postural control and gait speed disturbances above that expected to occur through the normal aging process. The causative mechanism may include: impaired cervical muscle and joint receptors; muscle fatigue; inflammatory induced deficits in muscle spindle coordination, nociceptor and mechanoreceptor pain modulation locally, regionally (spinal cord) or globally (CNS); as all have the potential to generate altered afferent input.
Boucher, Descarreaux, and Normand (2008) investigated postural control in participants with advanced cervical OA (mean age of 64) \((n = 9, \text{G1})\), with none to mild cervical OA (mean age of 59.3) \((n = 7, \text{G2})\), and young asymptomatic participants without any sign of OA (mean age of 24.2) \((n = 7, \text{G3})\). This study was formulated to investigate the relationship between the clinical symptoms of cervical OA and possible decreases in postural control between the groups. They determined significantly decreased postural control in the advanced cervical OA participants compared to both G2 and G3, no significance was determined between the two latter groups. No difference in subjective pain scores was identified between G1 and G2 during testing; however, clinical signs of lower limb neuropathy was observed in the OA groups. The authors suggested decreased postural control may be credited with the lower limb neuropathy alone, or in combination with impaired proprioceptive input related to the degeneration in the cervical spine. Vuillerme and Pinsault (2009) investigated the effect of experimentally induced neck pain on postural control in asymptomatic male participants with a mean age of \(22.2 \pm 1.8\ (n = 16)\). The authors concluded significantly deceased postural control was observed during the induced neck pain session in relation to the pain free session. These findings highlight the negative effect of neck pain on the maintenance of functional postural control mechanisms.

Palmgren, Andreasson, Eriksson, and Hagglund (2009) investigated cervicocephalic kinesthetic sensibility and postural control in participants with chronic NSNP \((n = 13)\) and asymptomatic participants \((n = 16)\) with a mean age of 37.0, concluding only one of six repositioning tests demonstrated significance while significantly decreased postural control was observed during tandem stance with closed eyes testing. Palmgren et al. (2009) suggested no evidence of impaired postural balance was shown, as postural sway exhibited wide-ranging differences in all tests both within and between groups.
Yahia et al. (2009) investigated whether chronic NSNP sufferers with vertigo and instability have decreased postural control in participants with chronic NSNP with vertigo \((n = 32, \text{G1})\), chronic NSNP no vertigo \((n = 30, \text{G2})\) and asymptomatic participants with a mean age of 47.5 \((n = 30, \text{G3})\). The authors concluded significantly decreased postural control was demonstrated in chronic NSNP with vertigo compared to G2 and G3. Interestingly no significant difference was demonstrated between G2 and G3, which is concerning considering the findings of many studies that suggest there should be a difference. Yahia et al. (2009) suggested the presence of neck-related headache and reduced cervical spine flexibility may have contributed to the impaired cervical proprioception and decreased postural control observed in G1 and not in G2. Uthaikhup, Jull, Sungkarat, and Treleaven (2012) investigated elderly postural control in participants with neck pain \((n = 20)\) and asymptomatic participants aged 65 or older \((n = 20)\) concluding elderly participants with neck pain exhibit decreased postural control when compared to age-matched asymptomatic participants. Uthaikhup et al. (2012) suggest these findings indicate that altered afferent information originating from the cervical spine can be responsible for decreased postural control.
Ruhe et al. (2011) published what appears to be the first comprehensive literature review investigating the relationship between postural sway and neck pain, reviewing the findings of 10 studies. All studies assessed CoP parameters on a force platform, representing the standard index for evaluating postural control. Neck pain participants exhibited either NSNP or WAD (traumatic neck pain), and assessment involved contrasting the two neck pain groups against each other or either group against the asymptomatic participants. Ruhe et al. (2011) concluded, due to the heterogeneous nature of the study’s designs, only a general trend was identifiable, that being WAD and NSNP participants display decreased postural control compared to asymptomatic participants. Ruhe et al. (2011) indicated the CoP findings represented a continuum with WAD participants exhibited the greatest levels of decreased postural control within the three groups while asymptomatic participants exhibited the greatest levels of postural control, and NSNP participants reside somewhere is the middle of the continuum.

Silva and Cruz (2013) followed up the Ruhe et al. (2011) review and performed a second systematic literature review to ascertain if postural control parameters differ between WAD, NSNP and asymptomatic participants. Silva and Cruz (2013) reviewed the findings of 12 studies, including 7 previously unreviewed and 5 previously reviewed by Ruhe et al. (2011). Tables 2.1 and 2.2 identifies the 17 independent studies reviewed by these two research teams. Silva and Cruz (2013) confirmed the findings of the Ruhe et al. (2011) review and concluded a CoP continuum exists with WAD participants exhibiting greater levels of decreased postural control compared to NSNP participants; however, both neck pain groups exhibit decreased postural control compared to asymptomatic participants. Tables 2.1 and 2.2 were further refined to identify several aspects related to these two key systematic reviews.
Overview of the Systematic Literature Review: Altered Postural Sway in Patients Suffering From Non-Specific Neck Pain and Whiplash Associated Disorder (Ruhe et al., 2011).

<table>
<thead>
<tr>
<th>Reviewed Studies (n = 10)</th>
<th>Asymp</th>
<th>NSNP</th>
<th>WAD</th>
<th>Mean Age</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>McPartland et al. 1997</td>
<td>n = 7</td>
<td>n = 7</td>
<td></td>
<td>39.2</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Treleaven et al. 2005 [#]</td>
<td>n = 50 G3</td>
<td>n = 50 G1</td>
<td>n = 50 G2</td>
<td>33.8</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Vuillerme et al. 2009</td>
<td>n = 7</td>
<td></td>
<td>A-Induced</td>
<td>22.2</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Michaelson et al. 2003 [#]</td>
<td>n = 9</td>
<td></td>
<td>41.7</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td>Field et al. 2008 [#]</td>
<td>n = 30</td>
<td>n = 50 G1</td>
<td>n = 50 G2</td>
<td>28.3</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Madeleine et al. 2004</td>
<td>n = 11</td>
<td>n = 11</td>
<td></td>
<td>33.2</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Poole et al. 2008 [#]</td>
<td>n = 20</td>
<td></td>
<td></td>
<td>70.9</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Endo et al. 2008</td>
<td>n = 20</td>
<td>n = 32</td>
<td></td>
<td>38.5</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Storaci et al. 2006</td>
<td>n = 40</td>
<td>n = 40</td>
<td></td>
<td>31.2</td>
<td>Not Described Statistically</td>
</tr>
<tr>
<td>Treleaven et al. 2008 [#]</td>
<td>n = 20</td>
<td>n = 20</td>
<td></td>
<td>48</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
</tbody>
</table>

[#] = Studies also Reviewed in Table 2.2. SS = Statistical Significance, > = Greater Than, G = Group, Asymp = Asymptomatic, NSNP = Non-Specific Neck Pain, WAD = Whiplash Associated Disorder, A-Induced = Asymptomatic-Induced, CoP = Centre of Pressure, n = Number of Participants, Sig = Significant.
Table 2.2.  

<table>
<thead>
<tr>
<th>Reviewed Studies (n = 12)</th>
<th>Asymp</th>
<th>NSNP</th>
<th>WAD</th>
<th>Mean Age</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boucher et al. 2008</td>
<td>n = 7 G3</td>
<td>n = 9 G1</td>
<td>64.0 G1</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n = 7 G2</td>
<td></td>
<td>59.3 G2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24.2 G3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobo et al. 2009</td>
<td>n = 45</td>
<td>n = 54</td>
<td>32.4</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td>Dehner et al. 2008</td>
<td>n = 40</td>
<td>n = 40</td>
<td>29.0</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td>Field et al 2008 [#]</td>
<td>n = 30</td>
<td>n = 30</td>
<td>n = 30</td>
<td>28.3</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Madeleine et al. 2010</td>
<td>n = 11</td>
<td>n = 11</td>
<td>33.2</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td>Michaelson et al. 2003 [#]</td>
<td>n = 16</td>
<td>n = 9</td>
<td>n = 9</td>
<td>41.7</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palmgren et al. 2009</td>
<td>n = 16</td>
<td>n = 13</td>
<td>37.0</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td>Poole et al. 2008 [#]</td>
<td>n = 20</td>
<td>n = 20</td>
<td>70.9</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td>Treleaven et al. 2005b [#]</td>
<td>n = 50 G3</td>
<td>n = 50 G1</td>
<td>33.8</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treleaven et al. 2005c</td>
<td>n = 20</td>
<td>n = 20</td>
<td>30.0</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td>Treleaven et al. 2008 [#]</td>
<td>n = 20</td>
<td>n = 20</td>
<td>48</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td>Yahia et al. 2009</td>
<td>n = 30</td>
<td>n = 32 G1</td>
<td>47.6</td>
<td>SS in 1 or &gt; CoP Parameter</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30 G2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[#] = Studies also Reviewed in Table 2.1. SS = Statistical Significance, > = Greater Than, G = Group, Asymp = Asymptomatic, NSNP = Non-Specific Neck Pain, WAD = Whiplash Associated Disorder, A-Induced = Asymptomatic-Induced, CoP = Centre of Pressure, n = Number of Participants, Sig = Significant.
Table 2.3.
*Overview of Two Systematic Literature Reviews Comparing Postural Control in Participants Suffering Whiplash Associated Disorder.*

<table>
<thead>
<tr>
<th>Reviewed Studies (n=11)</th>
<th>Asymp Mean Age</th>
<th>WAD Mean Age</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michaelson et al. 2003</td>
<td>n = 16 41.7</td>
<td>n = 9 41.7</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Field et al. 2008</td>
<td>n = 30 28.3</td>
<td>n = 30 28.3</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Madeleine et al. 2004</td>
<td>n = 11 33.2</td>
<td>n = 11 33.2</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Endo et al. 2008</td>
<td>n = 20 38.5</td>
<td>n = 32 38.5</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Storaci et al. 2006</td>
<td>n = 40 31.2</td>
<td>n = 40 31.2</td>
<td>Not Described Statistically</td>
</tr>
<tr>
<td>Treleaven et al. 2008</td>
<td>n = 20 48.0</td>
<td>n = 20 48.0</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Cobo et al. 2009</td>
<td>n = 45 32.4</td>
<td>n = 54 32.4</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Dehner et al. 2008</td>
<td>n = 40 29.0</td>
<td>n = 40 29.0</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Madeleine et al. 2010</td>
<td>n = 11 33.2</td>
<td>n = 11 33.2</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Treleaven et al. 2005b</td>
<td>n = 50 G3 33.8</td>
<td>n = 50 G1 33.8</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Treleaven et al. 2005c</td>
<td>n = 20 30.0</td>
<td>n = 20 30.0</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Pooled Data All Studies</td>
<td>n = 303 34.5</td>
<td>n = 367 34.5</td>
<td>90.9% SS</td>
</tr>
</tbody>
</table>

SS = Statistical Significance, > = Greater Than, G = Group, Asymp = Asymptomatic, WAD = Whiplash Associated Disorder, CoP = Centre of Pressure, n = Number of Participants.

The pooled data summarised in Table 2.3 identified 11 studies investigated postural control between WAD (n = 303) and asymptomatic participants (n = 367) with a mean age of 34.3 across both groups and 10 studies indicating significant findings. The pooled data summarised in Table 2.4 identified 9 studies investigating postural control between NSNP (n = 175) and asymptomatic participants (n = 144), with a mean age of 44.3 and 38.3 respectively, with two studies indicating no significant findings. de Zoete et al. (2017) performed an extremely interesting systematic review and meta-analyses examining whether postural control testing can identify, then quantify, differences between NSNP sufferers and asymptomatic participants. The de Zoete et al. (2017) review included pooled postural sway area data from 10 studies during both eyes open and eyes closed testing on sample sizes
ranging from 9 to 107 participants. The meta-analyses were unable to demonstrate significance between postural sway testing for NSNP and asymptomatic participants; however, individual studies showed statistical significance between these groups.

Table 2.4.
*Overview of Two Systematic Literature Reviews Comparing Postural Control in Participants Suffering Non-Specific Neck Pain.*

<table>
<thead>
<tr>
<th>Reviewed Studies (n = 9)</th>
<th>Asymp</th>
<th>Mean Age</th>
<th>NSNP</th>
<th>Mean Age</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>McPartland et al. 1997</td>
<td>n = 7</td>
<td>39.2</td>
<td>n = 7</td>
<td>39.2</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Vuillerme et al. 2009</td>
<td>n = 7</td>
<td>22.2</td>
<td>A-Induced</td>
<td>22.2</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Field et al. 2008</td>
<td>n = 30</td>
<td>28.3</td>
<td>n = 30</td>
<td>28.3</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Madeleine et al. 2004</td>
<td>n = 11</td>
<td>33.2</td>
<td>A-Induced</td>
<td>33.2</td>
<td>No Sig Difference</td>
</tr>
<tr>
<td>Boucher et al. 2008</td>
<td>n = 7 G3</td>
<td>24.2 G3</td>
<td>n = 9 G1</td>
<td>64.0 G1</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n = 7 G2</td>
</tr>
<tr>
<td>Michaelson et al. 2003</td>
<td>n = 16</td>
<td>41.7</td>
<td>n = 9</td>
<td>41.7</td>
<td>No Sig Difference</td>
</tr>
<tr>
<td>Palmgren et al. 2009</td>
<td>n = 16</td>
<td>37.0</td>
<td>n = 13</td>
<td>37.0</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Poole et al. 2008</td>
<td>n = 20</td>
<td>70.9</td>
<td>n = 2</td>
<td>70.9</td>
<td>SS in 1 or &gt; CoP Parameter</td>
</tr>
<tr>
<td>Yahia et al. 2009</td>
<td>n = 30</td>
<td>47.6</td>
<td>n = 32 G1</td>
<td>47.6</td>
<td>SS in 1 or &gt; CoP Parameter</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n = 30 G2</td>
</tr>
<tr>
<td><strong>Pooled Data All Studies</strong></td>
<td>n = 144</td>
<td>38.3</td>
<td>n = 175</td>
<td>44.3</td>
<td>77.8% SS</td>
</tr>
</tbody>
</table>

SS = Statistical Significance, > = Greater Than, G = Group, Asymp = Asymptomatic, NSNP = Non-Specific Neck Pain, A-Induced = Asymptomatic-Induced, CoP = Centre of Pressure, n = Number of Participants, Sig = Significant.

de Zoete et al. (2017) indicated comparable postural sway protocols were performed; however, the wide range in data, especially in NSNP (Figure 2.13), may result from variances within exact intra and inter-study protocols, equipment, participant demographics and measurement errors. de Zoete et al. (2017) suggested controlling the degree of variability across studies, and test settings may have produced the findings within this meta-analysis.
The literature appears to indicate that although statistically significant differences are reported in many studies, the total sway data itself when compared between NSNP sufferers and asymptomatic participants is unable to significantly distinguish the two groups.

Figure 2.13. Postural sway area parameters between non-specific neck pain and asymptomatic participants. No significant differences between means and interquartile ranges for postural sway (eyes open: \( p=0.16 \), eyes closed: \( p=0.30 \)), adapted from (de Zoete et al., 2017).

This compendium of the literature suggests from a spike at approximately the age of 30, postural control naturally and progressively decreases to the age of approximately 60, at which point a rapid acceleration in decreased postural control appears to transpire. On average, across all ages, females exhibit increased postural control parameters relative to
male participants. Compared to elderly, asymptomatic participants, similarly aged neck pain sufferers exhibit decreased postural control. It has been suggested that possible causative mechanisms in the elderly include nociceptor and mechanoreceptor pain modulation locally, regionally and globally, inflammatory induced deficits in muscle spindle coordination, muscle fatigue, impaired cervical muscle and joint receptors, which all potentially degrade cervical afferent input. Elderly neck pain sufferers with advanced cervical OA demonstrate lower limb neuropathies; suggestions have been made that decreased postural control may be credited to this comorbidity alone, or in combination with, impaired proprioception.

Chronic NSNP sufferers have been shown to exhibit decreased postural control and bilateral fat-infiltrated atrophied suboccipital muscles, suggesting a structural element related to impaired proprioceptive input. Associated conditions related to chronic NSNP can include vertigo, neck-related headache and cervical inflexibility, and it has been speculated that this condition contributes to impaired proprioception. Neck pain experimentally induced significantly deceased postural control in asymptomatic participants during one study, while no significance was demonstrated during another study. No evidence of decreased postural control was observed in one study in which participants exhibited wide-ranging differences in all tests, both within and between groups. The literature overwhelmingly supports aberrant cervical afferent input, regardless of its origin, as perhaps the primary cause of decreased postural control in both NSNP and WAD sufferers.

Reviews by Ruhe et al. (2011) and Silva and Cruz (2013) provide convincing evidence that decrease postural control variability in participants with neck pain appears to be associated with the etiology of the condition and the extent of the proprioceptive impairment. CoP findings represented a continuum. The greatest levels of decreased postural control are
evidenced in WAD participants, followed by NSNP participants, and finally asymptomatic participants exhibited the greatest levels of postural control, thus accurately representing proprioceptive input.

Quek, Treleaven, Clark, and Brauer (2018) recently demonstrated decreased postural control with a sample of NSNP sufferers compared to asymptomatic participants, offering the most recent conclusion to date that decreased postural control in older adults with NSNP may not be related to lower limb sensorimotor function, the level of physical activity undertaken, or either visual contrast sensitivity or vestibular function. The authors emphasise decreased postural control is almost certainly due to pain and the concomitant neuromusculoskeletal impairments that result in aberrant afferent input to the sensorimotor control system. Sensory reweighting, whereby compensatory lower limb proprioception is depended upon more than it typically would to make up for the short fall in impaired cervical proprioception, allows the maintenance of the centre of gravity within the base of support. This compensatory mechanism may attempt to account for the proprioceptive feedback time delay by increasing the stiffness of the lower limb and hip joints, thus possibly explaining these findings of increased postural sway and decreased postural control. Quek et al. (2018) states “There is limited understanding of potential mechanisms underpinning postural control deficits in people with neck pain”. Ruhe et al. (2011) pointed out that the neck pain groups were ideally contrasted against each other or asymptomatic participants. Crucially, concerning the Quek et al. (2018) statement, even less understanding is known about or discussed within the literature regarding the asymptomatic transition into NSNP. It is for this reason that this review investigates the relationship between the cervical spine and asymptomatic postural control.
2.11 Cervical Alignment and Asymptomatic Postural Control

Tanaka, Uetake, Kuriki, and Ikeda (2002) performed an extremely unique study investigating postural control in asymptomatic male college students (mean age 18.6 ± 0.69; \( n = 682 \)). Prior to the formal force platform test, the participants performed a one-leg balance test with eyes closed; this testing determined, through their balance potential, the sample set. Twenty asymptomatic participants were selected and divided into 2 groups: (1) the off-balance group \( (n = 10) \) and, (2) the balance group \( (n = 10) \), with no significance was observable between the physical fitness profile of each group. Tanaka et al. (2002) were able to demonstrate markedly decreased balance control within members of a single cross-sectional asymptomatic cohort with similar physical fitness profiles. However, Tanaka et al. (2002) did not discuss theoretical causative mechanisms for their results, but this finding appears to be the first reported occurrence in which asymptomatic participants exhibited extreme variability with postural control parameters.

Kang et al. (2012) were the first to publish an investigation into the relationship between FHP, computer usage and postural control in asymptomatic participants with Group 1 \( (n = 30) \) having a mean number of hours per day of computer use and years employed in a computer-related occupation of 6.4 and 11.5 respectively, and Group 2 (control, \( n = 30 \)) having a mean number of hours per day of computer use < 1 over the same time period (mean age of 34.9). They performed sagittal photogrammetric measures including the CVA in a seated position after two hours of computer work to determine the extent of the participants’ FHP (Figure 2.14A). They established the CVA within Groups 1 and 2 to be 48.9° ± 4.3° and 51.9° ± 5.5° respectively \( (p < 0.05) \), demonstrating participants employed in computer-related occupations exhibit a predominance towards an anteriorly translated cervical spine.
representing FHP. The authors identified significantly decreased postural control and anteriorly located CoM placement in Group 1 exhibiting FHP compared to Group 2 with no FHP. Significance was demonstrated during conditions 5 and 6 while the force platform swayed with either a fixed screen (5) or moving screen with open eyes (6) (Figure 2.14B). The authors suggested heavy computer users with FHP possess an anteriorly shifted posture imbalance that reduces their relative motor control ability allowing decreased postural control to be exhibited although an asymptomatic statue predominates.

J. H. Lee (2016) recently investigated the effects of photogrammetric determined FHP on static and dynamic postural control in asymptomatic participants with FHP (CVA < 53°; n = 14) and in the Control Group (CVA ≥ 53°; n = 16) (mean age of 21.9). They demonstrated decreased postural control performed statically between participants with FHP compared to participants without FHP. Decreased postural control was evident on both hard and sponge surfaces while participants’ eyes where either open or closed during CoP total sway distance. The authors suggested that participants with FHP have developed an underlying structural change within their neuromusculoskeletal system that is detrimental to functional postural control. Additionally, due to the greater difference in decreased postural control observed between tests with their eyes open and those with their eyes closed, visual mechanisms may play a vital role in asymptomatic postural control.
Figure 2.14. Asymptomatic postural control protocols. **A.** Seated sagittal photogrammetric measures including the craniovertebral angle. **B.** Six conditions of sensory organization testing using a variety of combinations: eyes open or closed, a fixed or moving screen and a stable or swaying force platform, adapted from (Kang et al., 2012).

Karajgi et al. (2015) investigated the effects of CVA determined FHP on static postural control in asymptomatic participants with FHP (CVA < 50°; n = 25) and in the Control Group (CVA ≥ 50°; n = 25) (aged 18 to 25). The authors demonstrated in static postural control trials on both hard and sponge surfaces, with eyes open and closed, that participants with FHP exhibit greater differences in CoP parameters; however, the differences were not enough to demonstrate statistical significance.

Silva and Johnson (2013) investigated the effects induced FHP has on postural control compared to their natural head posture in asymptomatic participants (mean age 20.8 ± 2.2; n = 25). Participants were tested using a force platform while assuming their natural head posture, then retested while holding their head in an anteriorly translated position, representing a 6° FHP. Silva and Johnson (2013) identified no discernible alteration in postural control between a participant’s natural head posture and induced FHP. Silva and Johnson (2013) suggested assuming a neck posture does not alter the underlying sensorimotor integration system to the extent required to effect postural control. The literature is scarce in
relation to the cervical spine and asymptomatic postural control. Regardless of this limitation, the literature that is available appears to provide evidence that markedly decreased postural control CoP parameters exist in single cross-sectional asymptomatic samples. It appears acquired FHP has the capacity to potentiate decreased postural control in asymptomatic participants.

Researchers within this domain have proposed a prolonged mechanistic alteration in the underlying structural alignment of the cervical spine as the primary causative means by which the asymptomatic neuromusculoskeletal system exhibits detrimental coordination potentials. Additionally, visual mechanisms may play a vital role in asymptomatic postural control, as greater levels of decreased postural control are observed when testing is conducted with eyes closed. Induced FHP in asymptomatic participants was unable to identify decreased postural control when compared to their natural head posture. This finding importantly supports prolonged variations in cervical spine alignment potentially triggering asymptomatic altered sensorimotor integration to the point at which decreased postural control is observable in participants with sustained FHP.
2.12 Non-Specific Neck Pain: A Transition from an Asymptomatic State

Researchers have proposed that painless spinal problems can develop in the general population without any nociceptive knowledge that anything is untoward, or an underlying condition is even manifesting (Haavik-Taylor & Murphy, 2007). Painless conditions may gradually and permanently alter the way the brain processes and responds to sensory information (Haavik-Taylor & Murphy, 2007; Shakespeare, Stokes, Sherman, & Young, 1985). There is mounting evidence that spinal dysfunction, irrespective of its magnitude, has the potential to affect neural processing, leading to altered afferent input to the CNS. Altering sensorimotor integration establishes and perpetuates plastic changes in the CNS and the manner in which it reacts to successive afferent input, thus generating an aberrant sensorimotor integration loop (Haavik-Taylor & Murphy, 2007).
2.13 The Concluding Synopsis: Answering the Primary Research Question

This literature review was conducted to determine the background knowledge of each domain relating to asymptomatic participants exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype. The fundamental components that relate to this issue, whether practical or theoretical, were explored.

Regarding the asymptomatic human spine, simply put it is a linear chain linking the head to the pelvis; however, that is where the simplicity stops. Sagittal spinal alignment appraisal is comprehensive. Its regional parameters are extremely wide, and global alignment is tremendously individualised. Large sagittal ranges represent a direct consequence of regional alterations refashioning the neighbouring segments and regions of the spinal column and/or pelvis. A unique co-dependency exists between regional curves and their vertical orientation, the sole function of this relationship is to allow spinal balance to reach equilibrium. Global spinal balance, as a single parameter, is maintained in the narrowest range of all the spinal parameters, being restricted to a small alignment range over the pelvis and femoral heads and permitting functional balance to transpire.

A consensus is clear within the literature that the cervical lordotic curvature represents the “physiological” or “normal” alignment state. The cervical region dominates spinal mobility in every sense of the word; its regional movement capacity is unparalleled while encompassing the largest range of any single spinal parameter, the ARA $c_2$-$c_7$ ($11^\circ$ of kyphosis to $45^\circ$ of lordosis). Albeit the notion of a physiologically functioning cervical lordotic state prevailing within us all is embraced, it is seemingly plausible that most of humanity’s asymptomatic youth currently live with an entrenched cervical non-lordotic
alignment pattern. Intuitively, six decades ago the first radiographic cervical spine investigation determined a straight cervical spine was abnormal, while a cervical kyphotic curve was pathological. Subsequently, three and a half decades have past between the first radiographic investigation in 1960 and a comprehensive appreciation of the cervical spine’s descriptive and depicted alignment characteristics appearing in the literature.

Over the past twenty years the literature has recognised cervical straight, kyphotic, sigmoidal and reverse sigmoidal curves as non-lordotic in nature. Recently our understanding within this domain has expanded substantially, revealing non-lordotic subtypes promote the pathogenesis and rate of progression associated cervical osseous and myelopathic degeneration. Non-lordotic development is a slowly adapting asymptomatic alignment alteration seemingly triggered by significant time spent assuming cervical flexion such as by those involving screen-based activities. Non-lordotic transformation evolves within existing lordotic spines, or independently as the primary alignment subtype during sagittal spine ontogeny, the latter embracing greater support. Head-on-trunk movement and postural control accuracy is unattainable without health functional sensorimotor integration.

It is unambiguous within the literature, a well-defined mechanistic mechanism of association links non-lordotic subtypes and neck pain, and particularly NSNP. It is now self-evident that neck pain equates to impaired cervical proprioception to some extent, and proprioceptive impairment is assumed to positively influence persistent pain. Impairment is often referred to as aberrant cervical afferent input, which detrimentally affects sensorimotor integration, thus somatic coordinate motion. Regardless of the reviewed study outlined in Table 2.4, decreased sensorimotor integration accuracy associated with NSNP postural control CoP parameters or cervical JPS errors (de Zoete et al., 2017), has primarily been
contributed to altered cervical afferent input. It is verified repeatedly, and accepted widely, that neck pain, regardless of its etiology, affects head movement accuracy and decreases postural control when compared to asymptomatic participants.

Asymptomatic participants with greater FHP have recently been shown to possess impaired head movement accuracy and decreased postural control compared to age-matched samples without FHP, indicating some level of structurally induced asymptomatic “precursor” aberrant cervical afferent input is affecting sensorimotor integration processes. Painless spinal problems develop in the general population. There is a measure of inevitability that painless spinal problems will progress into painful symptomatic syndromes. A NSNP transitional triggering mechanism of association must evolve in previously asymptomatic children and adolescents to permit the level of symptomatology reported within the longitudinal literature. Beyond the repetitively reworked version of causation being aberrant cervical afferent input, the precise neurological mechanisms of association involving asymptomatic transition into NSNP remain unknown. It is anticipated that positively answering the primary research question will strengthen our knowledge base regarding the structurally induced asymptomatic “precursor” impairment involving cervical afferent input.

The literature has permitted the identification of several characteristics that are consistently present within participants who exhibit aberrant cervical afferent input. It is a logical, and an exceedingly reasonable assumption, based on the available literature that all the somatic characteristics are present within the non-lordotic subtypes identified within this research project except one critical factor, pain itself. It is also rational to assume that if a “precursor” aberrant cervical afferent input is identified within all the asymptomatic non-
lordotic subtypes, the primary research question is answered, and an objective mechanism of association has been identified between asymptomatic “precursor” aberrant cervical afferent input and all the cervical non-lordotic subtypes. The key purpose of this literature review was to investigate domain-appropriate practical and theoretical content pertinent to the primary research question. It is clear supportive literature is available relating to this research project’s primary question and a positive finding will assist to fill the identified gap concerning the variability within CoP parameters in asymptomatic participants that currently exists.

The distinguishing feature of this research is the singularly selected asymptomatic adult sample being divided subsequently into two groups based solely on their radiologically classified cervical alignment subtype. Previous studies have assessed cervical alignment through photogrammetric measures, particularly the CVA, a measurement approach that may not provide critical information on the true nature of the underlying cervical vertebral alignment. Additionally, gross measures of cervical posture such as those assessed using photogrammetric measures fail to account for the numerous, alternative cervical non-lordotic conditions that can only be classified radiologically. These critical factors uniquely place this study within the literature that augments our knowledge concerning structurally induced asymptomatic “precursor” aberrant cervical afferent input. The importance of understanding the qualitative effects of asymptomatic “precursor” aberrant cervical afferent input related to cervical non-lordotic subtypes is a critical factor that may be of proactive benefit within the clinical environment of the future.
Chapter 3

3.1 Introduction

This chapter is presented in four-primary sections. The sections will be outlined in the chronological order of application as applied to this research project.

1. Recruitment Sourcing
2. Research Project Protocol
3. Eligibility Instruments: Standardised Surveys / Self-Reporting Questionnaire
4. Eligibility Instrument: Neuromusculoskeletal Physical Examination

Chapter 3 begins by detailing the ethic approval process undertaken followed by an outline of the numerous recruitment sources undertaken to acquire the 150 asymptomatic participants. This chapter outlines the protocols followed during this research project, detailing each of the three sessions undertaken by participants. Chapter 3 will conclude with a detailed breakdown of the accepted research eligibility instruments both passive (Survey Self-reporting) and active (Neuromusculoskeletal Physical Examination [PE]) employed during this research project to include or exclude participants into a credible asymptomatic research sample. The concluding section of this chapter will answer one of the secondary research questions proposed during this research project.
3.2 Human Ethics Approval

The Acting Chairperson of the Human Research Ethics Committee of the USC granted expedited ethics approval for this research project on the 2\textsuperscript{nd} of April 2014 (Appendix 2).

As a result of the two cervical radiographs required during the research project, participants received a dose of ionising radiation. In accordance with article 5.7.1.1 of The Code of Practice for the Exposure of Humans to Ionizing Radiation for Research Purposes (2005), the researchers employed a Medical Physicist to provide an ionising radiation dose calculation for that experienced by participants, stipulating level of dosage, safety issues, necessity of screening of potential participants, and wording required in informed consent materials.

3.2.1 Human ethics approval: A medical physicist’s ionising radiation report

Dr Leslie of the Gammasonic Institute for Medical Research supplied the ionising radiation dose calculation for this research (Appendix 3). The current study required volunteers to have A/P and Lateral cervical radiography using the techniques outlined by D. E. Harrison et al. (2003). Radiographic parameters were as follows based on commonly applied good practice and standard CR/Film speed of 400: Lat Cx: 75kV/20mA; AP Cx: 75kV/20mA.
Dr Leslie stated, "The expected dose for a single series in the research proposal is well below the dose constraints applied by the Australian Code of Practice". The dose is calculated: LAT Cervical 0.006 millisieverts (mSv), and the AP Cervical 0.007 mSv. The total dose for the two views is therefore 0.013 mSv (Table 3.1). The Australian Code of Practice outlines the effective dose for an adult in any year is 5 mSv, and the dose from this project was calculated to be 0.013 mSv representing 385 times less than the dose considered to be safe in a given year. Exposure to naturally occurring background radiation is approximately 2 mSv each year. This project’s dose is 154 times less than the level of exposure a normal person would receive from the environment naturally. At this dose level, no harmful effects of radiation have been demonstrated as any effect is too small to measure.

Table 3.1.
*Cervical Spine Absorbed Dose Per Radiographic View.*

<table>
<thead>
<tr>
<th>Radiographic View</th>
<th>Air Kerma at 1m (Gy)</th>
<th>Entrance Air Kerma (Gy)</th>
<th>Entrance Kerma (mGy)</th>
<th>Absorbed Dose per Gy</th>
<th>Absorbed Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAT Cervical</td>
<td>0.0005</td>
<td>0.00021</td>
<td>29</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>A/P Cervical</td>
<td>0.0005</td>
<td>0.00019</td>
<td>37</td>
<td>0.007</td>
<td></td>
</tr>
</tbody>
</table>

Gy = Gray, mGy = Milligray, mSv = Millisievert, LAT = Lateral, A/P = Anterior/Posterior.
3.3  Recruitment Sourcing: Overview

Recruitment sourcing is the use of one or more approaches to attract and identify participants to involve themselves in the research project. It may encompass internal and/or external recruitment comprising a variety of advertising mediums. For this study, participants were sourced from lectures and tutorials taught by the researcher and through snowballing via previously recruited participants and from the wider student body at the USC, to include participants who had no association with courses taught by the researcher.

3.3.1 Recruitment sourcing: USC media release

During May 2014, the media department at USC assisted with publicising the research project. Promoted on the University’s web page (https://www.usc.edu.au/explore/usc-news-exchange/news-archive/2014/may/phd-research-investigates-common-neck-pain). No participants recruited (Appendix 4).

3.3.2 Ethics Approval: WhyFitness magazine recruitment

The Acting Chairperson of the Human Research Ethics Committee of the USC granted expedited ethics approval for this research project to publish a recruitment advertisement in WhyFitness magazine on the 7th of April 2014 (Appendix 5).

3.3.3 Recruitment sourcing: WhyFitness magazine

A recruitment advertising article entitled, Neck Pain: How you can be part of the solution was published in WhyFitness magazine’s May edition (Appendix 6).
3.3.4 Recruitment sourcing: WhyFitness magazine, seminar

As part of the advertising package purchased through WhyFitness Magazine a fitness seminar was organised in early May 2014 to coincide with the launch of issue 11, in which I had advertised. No participants recruited (Appendix 7).

3.3.5 Ethics Approval: USC electronic noticeboard recruitment

The Acting Chairperson of the Human Research Ethics Committee of the USC granted expedited ethics approval for this research project to recruit via the USC electronic noticeboards on 6th May 2014 (Appendix 8).

3.3.6 Recruitment sourcing: USC electronic noticeboard recruitment

Student Life and Learning now known as The Centre for Support and Advancement of Learning and Teaching (C-SALT) organise notices on large television screens in strategic positions across USC. No participants recruited (Appendix 9).

3.3.7 Ethics Approval: USC web-based recruitment SONAR system

The Acting Chairperson of the Human Research Ethics Committee of the USC granted expedited ethics approval for this research project to recruit via the Universities web-based SONAR (Takepart) system on 28th July 2014 (Appendix 10).

3.3.8 Recruitment sourcing: USC web-based recruitment, SONAR system

A recruitment medium was developed by the research department at USC to inform potential participants about current research projects at the university. The platform was amalgamated into the research department’s web presence on the USC official web page. The SONAR System required a full description of the project to be developed and submitted to
the research department including a study name, brief abstract, a detailed description of the studies, eligibility requirements, duration and pre-study preparation. No participants recruited (Appendix 11).

3.3.9 Recruitment sourcing: USC static research notification board

USC provides one research notification board located on a prominent concrete pillar along a very busy thoroughfare on the main campus of the university. I developed a research flyer with tear away personal details vertically positioned on the bottom of the flyer. An effective recruitment strategy (Appendix 12).

3.3.10 Recruitment sourcing: USC rest room advertising

During the latter stages of the research project after completing approximately 90 participants; recruitments started to slow down. I observed an advertising flyer for an upcoming event to the back of the stall door in the rest room. A decision was made to place my research flyer (Appendix 12) on the back of the stall doors in the male and female rest rooms across the university’s campus. An effective recruitment strategy.

3.3.11 Recruitment sourcing: personalised research project business card

During the early stages of this research project students would occasionally approach me asking for my research details. I decide to approach recruitment like a business, ordering 500 business cards. I proceeded to hand out the cards to any potential participant. The cards worked on many levels, portraying a degree of speciality related to the research project, as no other research had used this procedure previously. The cards were easily transferred to student’s friends and family members. The cards were placed in card holders in key locations and attached to my research flyer on the research notification board. The research projects most effective recruitment strategy (Appendix 13).
3.4 Research Project Protocol: Overview

The subsequent overview is intended to layout the foundational structure of the testing sessions conducted during this research project. It is not intended to comprehensively describe every aspect of each test or procedure within their respective session, proceeding chapters of this thesis will perform this function.

While investigating the appropriate protocols required to successfully accomplish postural control research, it became evident that participant acquisition requires a strict standardised inclusion and exclusion criteria. Effectively performing consistent participant screening protocols without bias was achieved through a standardised sequencing procedure. Straker, O'Sullivan, Smith, and Perry (2009) outlined the preferred sequencing procedure that should be used during an initial research testing protocols session. A research project information sheet (Appendices 14) was provided via electronic means to all participants prior to attending the initial inclusion / exclusion session. Initially all passive activities should be completed including self-report questionnaires, standardised surveys and signing of consent form (Appendix 15), and this should be followed by the active activities such as the anthropometric measures and the PE. Once qualitative and quantitative variables have been recorded, Straker et al. (2009) recommend concluding the initial session by collecting the relevant research data through the designated research protocols, in the case of this research project these were the photogrammetric measures.

This research project was conducted over three sessions at two different physical locations. Participants were required to attend all three research sessions. Session 1 was conducted within the Biomechanics Laboratory at USC, with a time commitment of
approximately one hour. Session 2 was conducted off campus at a local chiropractic clinic where the radiographic examination was performed, with a time commitment of approximately 15 minutes. Session 3 was conducted at the same location as Session 1 and involved postural control testing with a time commitment of approximately 1.5 hours. The total time commitment for all three sessions within this research project was approximately 3 hours.

3.4.1 Research project protocol: Session 1

Prior to the first session, all participants were provided with the research project information sheet, all three health questionnaires and the consent form. Participants were asked to complete the health questionnaires and sign the consent form before attending the laboratory to improve the time efficiency during the first session. Most participants did not complete the attached documents prior to attending the first session, but instead chose to complete the documentation during the first session. In advance of any testing all participant documentation including the signed and dated consent form were initially scrutinised by the researcher with all concerning issues investigated meticulously. Participants were provided the opportunity to ask questions and have them answered, prior to any first session research protocols commencing. Establishing participant eligibility was the primary objective of Session 1, and during this session, all inclusion and/or exclusion protocols were performed with the explicit purpose of establishing the participant’s asymptomatic health status. The three health questionnaires were comprised of two standardised surveys and a project specific self-report questionnaire. All forms were available in hard copy for completion in the Biomechanics Laboratory on the day of testing if participants had not completed them before attending the laboratory.
3.4.1.1 Passive instruments

The standardised surveys used included:

- The Neck Disability Index (NDI) (Appendix 17).

The project-specific self-report questionnaires included:

- The Postural Sway Questionnaire (PSQ) (Appendix 18).
- Postural Sway Questionnaire Information Sheet (Appendix 19).

Additional paperwork:

- Consent to Participate in Research.

3.4.1.2 Active instruments

The active instrument used in this study was the Neuromusculoskeletal Physical Examination (Appendix 20).

3.4.1.3 Session 1: Data collection

Establishing participant eligibility was the primary objective of Session 1, and once this critical component was concluded and the participant’s asymptomatic health status confirmed, Session 1 data collection could commence. Data collection in Session 1 involved the procurement of photogrammetric measures. Photogrammetric measures are currently used to determine and evaluate natural stationary neutral craniovertebral postures. The procurement of valid comparable photogrammetric measures while assuming a neutral craniovertebral posture involves several physical and material aspects coming together seamlessly at one moment time. The physical aspects involve all the physical requirements the participant need to accomplish during the photogrammetric procurement process, whereas the material aspects involve the established photogrammetric area and equipment needed to facilitate valid photogrammetric procurement.
3.4.1.4  *Physical aspects of data collection*

- Foot Tracing.
- Self-Balance Procedure (Appendix 21).
- Photogrammetric Measurement Protocols.
  - Craniovertebral Angle (CVA).
  - Upper Cervical Gaze Angle (UCGA).
  - Lateral Head Tilt Angle (LHTA).

3.4.1.5  *Material aspects of data collection and processing*

- Photogrammetric Area.
- Photogrammetric Equipment.
- Photographic Measurement Software.
  - Able Image Analyser.

The physical and material aspects involved in procuring the photogrammetric measures are detailed and discussed in Chapter 4. Detailed background rationales are introduced in relation to all the relevant photogrammetric aspects which places the procedural techniques into their appropriate context. Chapter 4 expands on the physical and material aspects involved in procuring the photogrammetric measures and investigates whether photogrammetric techniques are reliably transferable during radiological acquisition to accurately validate cervical spine alignment. The two-secondary research questions associated with this chapter are examined, discussed and answered.
3.4.2 Research project protocol: Session 2

This session was conducted at a local chiropractic clinic which retained its own on-site radiographic equipment. The clinic, Living Well Chiropractic, was approximately a 7-minute walk from University. The researcher either walked with the participants from the University or meet the participants at the clinic. All radiographs were taken by the same radiographer, Dr David Shahar, with a digital capturing unit in accordance with the ionising radiation dose calculation for research purposes report. Digitization of all measures were performed on standard radiographic software (Genesis OmniVue® Genesis Digital Imaging, Inc. Los Angeles, CA) at a scale of 1.0, while images were imported to an external hard drive and printed, to allow cervical alignment classification via the Centroid Method.

3.4.2.1 Session 2: Data collection

Data collection in Session 2 involved the procurement of cervical radiographs to permit the determination of cervical subtype classification and specific radiographic measures. Cervical radiographs are currently considered the gold standard to determine the precise cervical alignment characteristic that enables accurate cervical subtype classification. The procurement of valid comparable cervical radiographs while assuming a neutral craniocervical posture were achieved through the application of strict standardised protocols.

3.4.2.2 Physical aspects of data collection

- Radiographic Participation Preparation.
- Radiographic Participation Positioning.
  - Anterior-Posterior Radiograph.
  - Lateral Radiograph.
3.4.2.3 Material aspects of data collection and processing

- Radiographic Digital Capturing Unit.
- Radiographic Measurement Software.
- Radiographic Classification Techniques.
  - The Centroid Method.
  - The Modified Takeshima/Herbst Method.

The physical and material aspects involved in procuring the radiographic classifications and measures are detailed and discussed in Chapter 5. Detailed background rationales are introduced in relation to all the relevant radiographic aspects which will place the procedural techniques into their appropriate context. Chapter 5 will expand on the physical and material aspects involved in procuring the radiographic images, and compare cervical subtype classification methods within an asymptomatic population. This Chapter 5 identifies inter-methodological consistencies and describe examples of inconsistencies that have the potential to affect subtype classification and clinical decision-making.

Chapter 5 is based on an article recently published: Daffin, L., Stuelcken, M. C., & Sayers, M. G. L. (2017). The efficacy of sagittal cervical spine subtyping: Investigating radiological classification methods within 150 asymptomatic participants. Journal of craniovertebral junction & spine, 8(3), 231. The two-secondary research questions associated with this chapter are examined, discussed and answered.
Following Session 2, the single asymptomatic cohort was segregated into two groups according to their radiographically classified cervical alignment subtype. Participants were classified as either lordotic or non-lordotic. Group 1 was constituted of 51 participants exhibiting a lordotic subtype while Group 2 was made up of 99 participants exhibiting any 1 of the 4 non-lordotic subtypes (Figure 3.1). The importance of understanding the two groups and their physical make up at this stage of thesis will become apparent during this chapter. The statistical data generated by all the passive and active instrument for each group is compared against one another’s, and the statistical data generated by the cohort. This process permitted statistical appraisal of the two groups in relation to cohort, allowing frank discussions and conclusions to be established in relation to any potential group bias related to a specific instrument and/or protocol following the establishment of the two groups.

Figure 3.1. A radiographic representation of the typical alignment patterns observed within each cervical subtype classifications. **Group 1:** Lordotic (L-type). **Group 2:** Straight (St-type), Global Kyphotic (GK-type), Sigmoidal (S-type), and Reverse Sigmoidal (RS-type) subtypes, radiographs by Lee Daffin.
3.4.2.4 Participant demographics

Among the 150 eligible participants there were 61 (40.7%) males and 89 (59.3%) females between the ages of 18 to 30. The cohort’s anthropometric demographics are presented in Table 3.2. Two participants both female, dropped out of the research project after session 2, failing to attend session 3. This data was rescinded and not included in the final analysis.

Table 3.2. Participant Anthropometric Demographics.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cohort ($n = 150$)</th>
<th>Male ($n = 61$)</th>
<th>Female ($n = 89$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Age (years)</td>
<td>22.5 (3.6)</td>
<td>22.7 (3.6)</td>
<td>22.5 (3.6)</td>
</tr>
<tr>
<td>Mean Height (cm)</td>
<td>170.7 (8.7)</td>
<td>177.5 (7.1)</td>
<td>166.1 (6.4)</td>
</tr>
<tr>
<td>Height Range (cm)</td>
<td>149.0 - 195.9</td>
<td>162.1 - 195.9</td>
<td>149.0 - 189.0</td>
</tr>
<tr>
<td>Mean Mass (kg)</td>
<td>70.1 (14.4)</td>
<td>79.1 (14.0)</td>
<td>63.9 (11.1)</td>
</tr>
<tr>
<td>Mass Range (kg)</td>
<td>45.0 - 128.0</td>
<td>53.3 - 128.0</td>
<td>45.0 - 95.5</td>
</tr>
</tbody>
</table>

M = Mean, SD = Standard Deviation, n = Number of Participants.

3.4.3 Research project protocol: Session 3

Centre of pressure data acquisition through postural control testing was the primary activity performed during Session 3. A Qualisys motion capture system (Qualisys AB, Gothenburg, Sweden) was used to record ground reaction force data from a 400 x 600mm force platform (Bertec Corporation, Columbus, USA). Participants were required to stand as still as possible on the force platforms during testing. During Session 3 participants were also required to undertake an additional foot tracing and photogrammetric measures in an identical approach to the methodologies followed during Session 1. At the end of Session 3 the participants had completed all the requirements necessary for this research project.
Data collection in Session 3 involved the procurement of postural control CoP parameters to permit the comparison of CoP parameters between the research two groups. Recording valid, comparable CoP parameters were achieved through the application of best practice, physical and material CoP protocols.

3.4.3.1.1 Physical aspects of data collection

- Postural Control Participation Preparation.
- Postural Control Participation Positioning.
  - Firm Surface (FS).
  - Compliant Surface (CS).

3.4.3.1.2 Material aspects of data collection and processing

- Postural Control Set-up Parameters.
- Postural Control Capturing Equipment.
  - Qualisys Motion Capture System (Qualisys AB, Gothenburg, Sweden).
  - Force Platform (Bertec Corporation, Columbus, USA).
- Biomechanical Analysis Software.
  - Visual3D, C-Motion, Inc. Maryland, USA.
The physical and material aspects involved in procuring the postural control CoP parameters are detailed and discussed in Chapter 6. Detailed background rationales are introduced in relation to all the relevant postural control aspects which places the procedural techniques into their appropriate context. Chapter 6 expands on the physical and material aspects involved in procuring postural control CoP parameters. Chapter 6 compares asymptomatic cervical alignment subtypes with CoP parameters and investigates the possibility of CoP parameters as acting as novel biomarkers for the detection of early cervical degeneration. The primary research question is associated with this chapter. The two groups CoP parameters are determined, and their findings are examined, discussed and the primary research aim is answered.
3.5 Eligibility Instruments: Standardised Surveys / Self-Reporting Questionnaire

It became apparent that postural control research involving the cervical spine consistently used two key standardised surveys to assess participants’ eligibility. The SF-36 is a general standardised survey that is extensively used across many different research settings involving human participants. It is not a specific cervical spine-related standardised survey, unlike the “NDI” which is specifically adapted to identify neck pathology.

A specific designated questionnaire with the capacity to identify asymptomatic participants for postural control research is non-existent. Within the methods section of relevant literature are many key pathological criteria used to either include or exclude participants from the research or asymptomatic (control) groups. It is from these key pathological criteria that a two page “PSQ” was formulated to fill this important gap and permit effective asymptomatic selection.

3.5.1 The medical outcomes study 36-item Short-Form Health Survey (SF-36)

Ware Jr and Sherbourne (1992) introduced a valid tool to gauge one’s health status, by scoring standardised responses to standardised questions. The SF-36 has been endorsed for use in clinical research and practice, health policy estimates and universal population surveys, representing the most extensively used non-specific screening tool for assessing quality of life (Schmitz & Kruse, 2007). Its validity has been demonstrated within various diverse samples and its design is unbiased regarding age, treatment and disease (McHorney, Ware, Lu, & Sherbourne, 1994; Peek, Ray, Patel, Stoebner-May, & Ottenbacher, 2004). Its reliability within non-English speaking countries is also well established (Sullivan, Karlsson, & Ware, 1995). These authors evaluated the psychometric properties of the SF-36 in a large
population study (n=8930) and determined the reliability of this questionnaire range from 0.83 to 0.93 across the 8 items. The bodily pain scale demonstrated the highest reliability estimate 0.93.

The multi-item scale investigates eight health concepts:

- Physical functioning
- Role limitations because of physical health problems
- Bodily pain
- Social functioning
- General mental health (psychological distress and psychological well-being)
- Role limitations because of emotional problems
- Vitality (energy/fatigue)
- General health perceptions

### 3.5.1.1 Medical study 36-item short-form health survey: Assessment

When assessing the SF-36 health survey, a larger score represents less pathology or fewer health concerns. A score of 100 would represent an ideal health status within that specific category. Mean SF-36 data for this research cohort are presented in a full cohort format, and is also segregated into the two research groups representing lordotic and non-lordotic subtypes. The mean SF-36 data was compared with the Australian Bureau of Statistics, 1995 National Health Survey SF-36 population normals, which did not provide standard deviation data (Australian Bureau of Statistics, 1995).
3.5.1.2 Medical study 36-item short-form health survey: Results

The mean values for the all assessed SF-36 categories were greater than the mean values indicated in the 1995 National Health Survey SF-36 population normals study (Australian Bureau of Statistics, 1995) indicating this research cohort exhibited an above normal health status (Table 3.3).

Table 3.3. Comparative Medical Outcomes Study 36-Item Short-Form Health Survey Data. Scores Range From 0 to 100.

<table>
<thead>
<tr>
<th>SF-36 Multi-Item Scale Health Concepts</th>
<th>Research Project, Age 18 - 30</th>
<th>National Health Survey SF-36 Age 18 - 34 Population Normals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full Cohort (n = 150) M(SD)</td>
<td>Lordotic (n = 51) M(SD)</td>
</tr>
<tr>
<td>Physical Functions</td>
<td>97.4 (5.4)</td>
<td>97.3 (5.7)</td>
</tr>
<tr>
<td>Physical Limitations</td>
<td>97.4 (9.5)</td>
<td>99.0 (4.9)</td>
</tr>
<tr>
<td>Pain</td>
<td>91.6 (11.0)</td>
<td>93.2 (9.5)</td>
</tr>
<tr>
<td>General Health</td>
<td>78.5 (14.9)</td>
<td>79.8 (14.2)</td>
</tr>
<tr>
<td>Vitality</td>
<td>68.5 (15.8)</td>
<td>69.4 (14.2)</td>
</tr>
<tr>
<td>General Mental Health</td>
<td>79.9 (24.1)</td>
<td>79.6 (10.9)</td>
</tr>
<tr>
<td>Emotional Problems</td>
<td>89.9 (24.1)</td>
<td>85.6 (27.7)</td>
</tr>
<tr>
<td>Social Functioning</td>
<td>91.4 (14.2)</td>
<td>93.4 (8.8)</td>
</tr>
</tbody>
</table>

1995 National Health Survey SF-36 population normals (Australian Bureau of Statistics, 1995), M = Mean, SD = Standard Deviation, SF-36 = Medical Outcomes Study 36-Item Short-Form Health Survey, n = Number of Participants.

3.5.2 The Neck Disability Index

Vernon and Mior (1991) published the “NDI”, a modification of the Oswestry Low Back Pain Index. It was the first index designed to assess self-rated neck disability. The questionnaire was designed to provide information as to how participants’ neck pain has affected their ability to cope in everyday life situations. Vernon and Mior (1991) concluded that its ease of application both in clinical and research settings has resulted in its endorsement by the Transport Accident Commission, Victoria, Australia; New South Wales
Motor Accidents Authority; British Columbia Physiotherapy Association; and, the Royal Dutch Society for Physical Therapists. The self-rated multi-item NDI investigates ten health concepts specifically concentrated on neck-related concerns. It has been peer reviewed and validated for self-rated neck pain (Vernon & Mior, 1991).

Young, Dunning, Butts, Mourad, & Cleland, (2018) investigated the reliability and construct validity of the psychometric properties included in the NDI. The authors determined within a mixed population (n=107) of participants displaying neck pain without associated upper extremity symptoms that the NDI exhibited excellent reliability 0.88. The authors also suggested their results were comparable to previous NDI studies conducted on similar participants therefore, an acceptable responsiveness to identify perceived disability and pain was shown.

The multi-item scale investigates ten neck specific health concepts:

- Pain Intensity.
- Personal Care.
- Lifting.
- Reading.
- Headache.
- Concentration.
- Work.
- Driving.
- Sleeping.
- Recreation.
The NDI is scored from 0 to a possible 100, the lower the score the healthier and more physical functionality the neck demonstrates. The ten neck health concepts are individually scored from 0 to 5, with zero representing an ideal health score and 5 representing severe pathology. Once completed, the scores are tallied and then doubled to represent a score out of 100. The scoring protocol during the NDI will only permit even scores to be formulated (Vernon & Mior, 1991). Kato et al. (2012) investigated the sensitivity of the NDI to correctly detecting participants with neck pathology and determined that a score of 15 and above exhibited the capacity to identify participants with neck pathology. The research findings of Kato et al. (2012) were used to establish the upper limit score of 12 /100 to accept participants for inclusion into this research project, as this score is considered to represent healthy individuals as it is too small to detect disability.

3.5.2.1  *The neck disability index: Results*

No participant included in this research project reported a score greater than 12 out of a possible score of 100. Table 3.4 represents the number of participants that reported each score between 0 and 12 as a full cohort, and segregated into the two research groups along with each score percentage related to the respective grouping. The NDI was shown to be an effective inclusion/exclusion instruments with the capacity to identify and exclude 6 participants from this research project with scores ranging from 16 to 24 out of a possible score of 100.
Table 3.4.  
*The Neck Disability Index: Participant Scores and Group Percentages for the Full Cohort and the Two Groups.*

<table>
<thead>
<tr>
<th>NDI Score</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Cohort (n = 150)</td>
<td>40</td>
<td>33</td>
<td>25</td>
<td>25</td>
<td>11</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Cohort Percentage</td>
<td>26.7%</td>
<td>22.0%</td>
<td>16.7%</td>
<td>16.7%</td>
<td>7.3%</td>
<td>2.7%</td>
<td>8.0%</td>
</tr>
<tr>
<td>Lordotic (n = 51)</td>
<td>14</td>
<td>12</td>
<td>10</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Group 1 Percentage</td>
<td>27.5%</td>
<td>23.5%</td>
<td>19.6%</td>
<td>17.6%</td>
<td>3.9%</td>
<td>0%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Non-Lordotic (n = 99)</td>
<td>26</td>
<td>21</td>
<td>15</td>
<td>16</td>
<td>9</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Group 2 Percentage</td>
<td>26.3%</td>
<td>21.2%</td>
<td>15.2%</td>
<td>16.2%</td>
<td>9.1%</td>
<td>4.0%</td>
<td>8.1%</td>
</tr>
</tbody>
</table>

NDI = Neck Disability Index, n = Number of Participants.

Table 3.5.  
*Raw NDI Findings For All Health Concepts Sequentially Presented for the Full Cohort and the Two Groups. Data Presented as n = Participants.*

<table>
<thead>
<tr>
<th>Raw NDI Score</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headache</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC</td>
<td>72</td>
<td>25</td>
<td>47</td>
<td>54</td>
<td>19</td>
<td>35</td>
<td>17</td>
</tr>
<tr>
<td>L</td>
<td>99</td>
<td>35</td>
<td>64</td>
<td>49</td>
<td>16</td>
<td>33</td>
<td>2</td>
</tr>
<tr>
<td>N-L</td>
<td>112</td>
<td>40</td>
<td>72</td>
<td>36</td>
<td>10</td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td>Reading</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC</td>
<td>113</td>
<td>38</td>
<td>75</td>
<td>32</td>
<td>12</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>L</td>
<td>127</td>
<td>46</td>
<td>81</td>
<td>23</td>
<td>5</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>N-L</td>
<td>141</td>
<td>48</td>
<td>93</td>
<td>9</td>
<td>3</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain Intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driving</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lifting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal Care</td>
<td>150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NDI = Neck Disability Index, FC = Full Cohort, L = Lordotic, 1, N-L = Non-Lordotic.
3.5.2.2  The neck disability index: Discussion and conclusion

As identified, the NDI is scored from 0 to 5; however, no participant scored higher than a 3 in any of the 10 neck health concepts. Table 3.5 represents the raw NDI findings for all 10 neck health concepts, with the results sequentially presented from the health item that attained the lowest zero score (worst outcome) to the one that achieved the highest (best outcome). An asymptomatic score of 12 was selected, which was less than the score of 15 recommended by Kato et al. (2012). The largest percentage for a single score being zero, which represents the ideal health score, was 26.7% \( (n = 40) \), while all scores between 8 and 12 exhibited cohort percentages of 8% or less. The only two health concepts that reported a raw score of 3 were headaches \( (n = 7) \) and sleeping \( (n = 2) \), while four health concepts: headache \( (n = 17) \), reading \( (n = 2) \), concentration \( (n = 2) \) and sleeping \( (n = 3) \) reported a raw score of 2. Personal care was the only health concept that every participant reported a score of zero, all other health concept reported a raw score of 1. In conclusion, the NDI scores reported for this research project suggest that this single cohort is asymptomatic in relation to the participant’s physical neck status and their ability to cope in everyday life situations without neck pathology affecting their quality of life.
3.5.3 Postural Sway Questionnaire

This comprehensive PSQ excluded any unsuitable participants who could potentially negatively influence any physical aspect of the data collection process. The PSQ was formulated with the objective of standardising the sample for this research project by increasing the validity of the cohort’s overall asymptomatic status. The two-page PSQ was formulated from the inclusion and exclusion criteria cited within the methods sections of 11 key domain appropriate articles (Cuccia & Carola, 2009; Field et al., 2008; M. B. Johnson & Van Emmerik, 2012; Kang et al., 2012; Kogler, Lindfors, Ödkvist, & Ledin, 2000; McPartland et al., 1997; Raine & Twomey, 1997; Silva & Cruz, 2013; Uthaikhup et al., 2012; Vuillerme, Pinsault, & Vaillant, 2005; Yu, Stokell, & Treleaven, 2011).

The pathological criteria used to either include or exclude participants included many health-related concerns and domain areas such as: cervical spine pathology comprising both acute and chronic symptomology, painful and/or limited cervical ROM, and cervical trauma including WADs. Full spine exclusion comprised chronic pain, congenital anomalies, scoliosis, surgery or pathology. Peripheral lower limb joint exclusion comprised any ruptured ligament, meniscal tears, diagnosed osseous degeneration, fractures and surgery inclusive of anterior cruciate ligament repair, meniscus removal or pathology. Any extensive periods of hospitalization or surgeries, other than orthopaedic repair, resulted in exclusion. Neurological exclusion comprised any balance disorder including dizziness, unsteadiness or vertigo, visual deficits and CNS pathology. Pharmaceutical drugs affecting the CNS, or having side effects resulting in sensorimotor, postural or balance dysfunction, resulted in exclusion. Absolutely any medically diagnosed disease, disease process or pathology including, but not limited to, inflammatory arthritic diseases, metabolic diseases and respiratory illness resulted in exclusion.
Participant were required to indicate if they were pregnant or breast feeding, had ever been exposed to toxic substances, needed to walk or stand with an aid such as a cane, or had a history of chronic alcohol or drug consumption/abuse. The PSQ was developed to essentially require only a simple “Yes” or “No” response for most of the questions presented. Answers that required a detailed description represented red flags, and warranted further questioning to determine the background history behind the participant’s response. Throughout the course of this research project, the PSQ was shown to be exceedingly effective at triggering potential participants’ memories related to their current and past health conditions.

**3.5.3.1 Postural sway questionnaire: Health habits and personal health information**

The last section of the PSQ required the participant to identify health habits and personal health information to assist in the overall development and appraisal of the participant’s health status. This section of the PSQ was not used as an inclusion and/or exclusion criterion; however, all questions were directly developed from the methods sections of the referenced literature used to develop the PSQ. The criteria investigated included: exercise, daily sitting postures at a computer and additional time spent sitting, caffeine, general health, alcohol and tobacco.

Table 3.6. *Weekly Exercise Involvement and Intensity Levels.*

<table>
<thead>
<tr>
<th>Exercise Intensity</th>
<th>Sedentary</th>
<th>Mild Exercise</th>
<th>Occasional Vigorous</th>
<th>Regular Vigorous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>3</td>
<td>27</td>
<td>42</td>
<td>78</td>
</tr>
</tbody>
</table>
The results concerning participants weekly exercise involvement and intensity levels are detailed in Table 3.6. In conclusion, 78, or greater than 50% of the cohort (52%), participants exercised 4 times per week for 30 minutes. Approximately 30% of the cohort (42; 28%) participants exercised less than 4 times per week for 30 minutes, while most of the remaining participants performed occasional mild exercise. These findings indicate the cohort was relatively physically active. Table 3.7 details participants daily sitting habits including individual habits such as, time spent at the computer and also additional sitting which incorporated any form of sitting posture assumed during the day. The two individual seated activities for every participant are correlated and reported in the combined total sitting data set. Over 50% of the cohort sits for at least six hours or more a day. The findings indicate that approximately 75% of the cohort spend 3 or more hours a day involved in screen-based activities. The significance of seated data are becoming apparent within the current literature.

Table 3.7.
Number of Hours Spent Seated During a Day: Reported as Individually Activities and Total Time Seated.

<table>
<thead>
<tr>
<th>Time Spent Seated Per / Day</th>
<th>Individual Activities Performed Seated</th>
<th>Seated while using Technology (Computer)</th>
<th>Additional Seated Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 to 2 hrs</td>
<td>3 to 4 hrs</td>
<td>&gt;5 hrs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Activities Seated</td>
<td>2 to 4 hrs</td>
<td>4 to 6 hrs</td>
<td>6 to 8 hrs</td>
</tr>
<tr>
<td>Combined</td>
<td>n = 17</td>
<td>n = 50</td>
<td>n = 57</td>
</tr>
</tbody>
</table>

Hrs = Hours, n = Number of Participants.
The results concerning participants’ alcohol and tobacco consumption are detailed in Table 3.8. The findings from this section of the PSQ were not used as inclusion or exclusion criterion. In conclusion, 139 (92.7%) participants reframed from smoking while 11 (7.3%) participants smoked. It was interesting that 39 (26%) participants neither consumed alcohol nor smoked; however, 100 (67%) participants consumed alcohol and did not smoke. Only 8 (5%) participants consumed alcohol and smoked; however, 3 (2%) participants smoked and do not consumed alcohol.

Table 3.8.  
Participants’ Alcohol and Tobacco Consumption.

<table>
<thead>
<tr>
<th></th>
<th>Alcohol</th>
<th>No Alcohol</th>
<th>Tobacco</th>
<th>No Tobacco</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td>n = 108</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Alcohol</td>
<td></td>
<td>n = 8</td>
<td></td>
<td>n = 100</td>
</tr>
<tr>
<td>Tobacco</td>
<td></td>
<td></td>
<td>n = 3</td>
<td>n = 39</td>
</tr>
<tr>
<td>No Tobacco</td>
<td></td>
<td></td>
<td></td>
<td>n = 139</td>
</tr>
</tbody>
</table>

\(n = \) Number of Participants.
3.5.3.2 Postural sway questionnaire: Results

While administering the PQS during the initial passive requirement section of session 1, 18 participants were excluded due to positive pathological conditions being identified by the PSQ (Table 3.9).

Table 3.9. Postural Sway Questionnaire Exclusion Rationale.

<table>
<thead>
<tr>
<th>Number</th>
<th>Exclusion Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Diabetes Mellitus Type 2</td>
</tr>
<tr>
<td>5</td>
<td>Whiplash Associated Disorder, Hospitalised motor vehicle accidents</td>
</tr>
<tr>
<td>4</td>
<td>Side effects from pharmacological medication: antidepressants</td>
</tr>
<tr>
<td>1</td>
<td>Surgical intervention: Bilateral tibial rotational osteotomy</td>
</tr>
<tr>
<td>1</td>
<td>Surgical intervention: Abdominal plastic surgery</td>
</tr>
<tr>
<td>18</td>
<td>Total number of participants excluded from the research project</td>
</tr>
</tbody>
</table>
3.6 Eligibility Instruments: Neuromusculoskeletal Physical Examination

The PE was conducted during Session 1 after the research project’s mandatory standardised surveys and self-reporting PSQ. The PE intended to serve two primary functions: (1) identification of asymptomatic participants with the physical capacity to partake in this research project, and (2) exclusion of participants with negative MSK manifestations that prevent the participant from meeting the strict, asymptomatic neuromusculoskeletal criteria. The importance of a comprehensive assessment protocol during a PE is imperative. It is for this reason that multiple aspects of the participant’s physical status were assessed. A comprehensive assessment protocol would be worthless if it was not performed by a skilled MSK practitioner able to interpret the small intra- and inter-participant nuances routinely observed during a PE. This research project’s primary researcher is a board certified and registered Doctor of Chiropractic with 25 years of education and practical experience assessing MSK pathology.

The PE was developed in conjunction with several board certified MSK practitioners from a variety of background, and validated with the current domain appropriate literature (Bickley & Szilagyi, 2012; Cipriano, 2010; Magee, 2014; Norkin & White, 2016). In the evidence-based MSK literature, likelihood ratios (LR) are commonly used to investigate the sensitivity and specificity of orthopaedic or neurological clinical tests, to determine the value of performing the test (Cook & Hegedus, 2012). The authors indicate likelihood ratios exist in two versions either positive or negative, the statistical measures of sensitivity (the probability of detecting a true positive result, LR+) and specificity (the probability of detecting a true negative result, LR-) are used to quantify these ratios. Alternatively, reliability and validity may be assessed in relation to the value of performing a clinical test (Magee, 2014).
Attention was devoted to the systematic sequencing of the specific tests within this PE protocol. It was determined that the testing order of this PE would minimise participant stress, improving positional convenience to maximise the efficiency of both examiner and participant. This sequencing also reduced the need for the participant to frequently change their test position, thus allowing a valid evaluation of the observed test outcome. The sequencing order of the specific tests allowed participants to progress from the initial global to regional standing tests through to the seated regional and specific tests. Initial evaluation, from a standing global perspective, allowed analysis of the participant’s natural physical status prior to any testing.

The tests performed in the PE are presented in the exact sequential order in which they were conducted. The tests included orthopaedic and neurological balance tests, standing shoulder active ROM, sitting cervical active and passive ROM testing, neutral cervical resisted isometric muscle testing, IVD compression and distraction testing and intervertebral foraminal compression testing. Examination results were recorded in relation to the specificity of the test performed. Certain tests were simply positive or negative, while ROM tests were recorded in degrees, and muscle testing were recorded as normal, pain or weakness. During the PE, the examiner’s discretion, established over years of testing patients or participants, permitted either inclusion or exclusion. Appreciation must be given during a PE to the presence of the grey area between positive and negative, therefore the capacity to add comments was included. Objectivity was never compromised during testing; however, on occasions, results of the PE recorded in the grey area were compared and contrasted against the SF-36, NDI and PSQ to determine either inclusion or exclusion (Flegel, 1999).
3.6.1 Anthropometric measurements: Handedness

Raine and Twomey (1997) indicated handedness should be identified, recorded and assessed, as it may be statistically significant when compared to other research parameters. While the participants were completing the project’s passive documentation, I observed the participant’s hand preference while writing. The participants were asked to confirm their dominant hand. Regardless of their individual hand preference while writing, the handedness acknowledged as the dominant hand by the participants was recorded. On several occasions, the less preferred, non-dominant hand was the hand used by the participant to complete the documentation. It has been estimated that approximately 10% of the population is left-handed (Hardyck & Petrinovich, 1977).

3.6.1.1 Handedness: Results and conclusion

This cohort demonstrated similar left-handedness (8%) to the general population, being approximately 10%. Both groups within this research project also demonstrated similar left-handedness to the general population (Table 3.10). In conclusion, this asymptomatic cohort, and its two segregated groups, all represent similar handedness to that observed within the general population.

Table 3.10. Hand Dominance for the Full Cohort and the Two Groups.

<table>
<thead>
<tr>
<th></th>
<th>Right Hand Dominance</th>
<th>Left Hand Dominance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Cohort (n = 150)</td>
<td>n = 138 (92%)</td>
<td>n = 12 (8%)</td>
</tr>
<tr>
<td>Lordotic Group 1 (n = 51)</td>
<td>n = 46 (90.2%)</td>
<td>n = 5 (9.8%)</td>
</tr>
<tr>
<td>Non-lordotic Group 2 (n = 99)</td>
<td>n = 92 (92.9%)</td>
<td>n = 7 (7.1%)</td>
</tr>
</tbody>
</table>

n = Number of Participants, Data Presented as n (% of cohort).
3.6.2 Anthropometric measurements: Height

*Height* is the vertical distance between the lowest and highest point of the barefoot participant while standing upright with their heels and knees together. The participant’s height was determined with a calibrated, permanently wall-mounted, mechanical stadiometer (Figure 3.2). The base unit of length used to record the participant’s height was the centimetre and its sub-unit the millimetre. The stadiometer consisted of vertical metal ruler that rolled up in its own compact plastic case. A plastic paddle was attachment to the case and adjusted to rest on the cranium’s vertex. Barefoot participants were instructed to place their back against the wall so the back of their head, scapulae, buttocks and heels lightly touched the measurement surface.

*Figure 3.2. Wall-mounted mechanical stadiometer, adapted from (http://tenhoo.en.hisupplier.com).*

If required, the participant’s position was slightly modified to align their mid sagittal plane to the midline of the stadiometer. Once in position further instructions included: stand relaxed, looking towards the horizon with your arms by your side, your legs straight and your knees and feet touching. The stadiometer’s plastic paddle was extended and placed on the cranial vertex at 90° to the measurement surface. This process was repeated several times until the stadiometer was positioned correctly against the measurement surface and cranial vertex. The measure was taken to the closest millimetre and recorded on the PE sheet.
3.6.2.1 Height: Results, discussion and conclusion

The participant height results for the full cohort and the two research groups are presented in Table 3.11. The mean height for the both research groups is similar to the mean height for the full cohort. The mean height for the lordotic group (173.5 ± 8.6) is slightly larger than the non-lordotic group (169.3 ± 8.5). One possible explanation for this finding is the larger percentage of male participants in the lordotic group (56.9%) and the larger percentage of female participants in the non-lordotic group (67.7%). In conclusion, the two research groups mean height values, along with the male and female mean height values, are similar to the cohorts’ mean height values, indicating that the two research groups have similar height characteristics to each other.

Table 3.11. Heights for the Full Cohort and the Two Groups.

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>M (SD)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>Minimum</td>
</tr>
<tr>
<td>Full Cohort (n = 150)</td>
<td>170.7 (8.7)</td>
<td>149.0</td>
</tr>
<tr>
<td>Full Cohort Male (n = 61, 40.7%)</td>
<td>177.5 (7.1)</td>
<td>162.1</td>
</tr>
<tr>
<td>Full Cohort Female (n = 89, 59.3%)</td>
<td>166.1 (6.4)</td>
<td>149.0</td>
</tr>
<tr>
<td>Lordotic Group 1 (n = 51)</td>
<td>173.5 (8.6)</td>
<td>155.9</td>
</tr>
<tr>
<td>Lordotic Group 1 Male (n = 29, 56.9%)</td>
<td>178.3 (6.5)</td>
<td>165.1</td>
</tr>
<tr>
<td>Lordotic Group 1 Female (n = 22, 43.1%)</td>
<td>166.5 (6.1)</td>
<td>155.9</td>
</tr>
<tr>
<td>Non-Lordotic Group 2 (n = 99)</td>
<td>169.3 (8.5)</td>
<td>149.0</td>
</tr>
<tr>
<td>Non-Lordotic Group 2 Male (n = 32, 32.3%)</td>
<td>176.7 (7.6)</td>
<td>162.1</td>
</tr>
<tr>
<td>Non-Lordotic Group 2 Female (n = 67, 67.7%)</td>
<td>166.0 (6.6)</td>
<td>149.0</td>
</tr>
</tbody>
</table>

M = Mean, SD = Standard Deviation, n = Number of Participants, Data Presented as n (% of cohort).
3.6.3 Anthropometric measurements: Mass

The mass (weight) of a participant was determined using a calibrated Tanita BWB-600 series digital medical scale (Figure 3.3). The scale has an automatic zero function when initially turned on. Once zeroed, the participant was instructed to stand on the weight platform. The participant mass was reported in kilograms and grams to one decimal place (1kg/100g). Once their weight was determined, the participant was instructed to step down off the platform.

3.6.3.1 Mass: Results, discussion and conclusion

The participant mass results for the full cohort and the two research groups are presented in Table 3.12. The mean mass for the full cohort (70.1 ± 14.4) resides between the larger lordotic group (73.4 ± 13.0) and lesser non-lordotic group (68.3 ± 14.9). The male and female percentages within the lordotic group (male, 56.9%) and non-lordotic group (female, 67.7%) directly influence the different mean mass values reported between the two research groups. The cohort’s mean mass values for both males and females are similar to the mean mass values reported in the two research groups. An equal male (n = 61) to female (n = 89) participant ratio may have brought the two groups’ mean mass values more in line with each other. Unfortunately, females within the younger decades have a tendency to exhibit larger numbers of cervical non-lordotic subtypes in relation to age-matched male populations (C. S. Lee et al., 2012; Yukawa et al., 2012).
Table 3.12.  
*Mass for the Full Cohort and the Two Groups.*

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>M (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Cohort ((n = 150))</td>
<td>70.1 (14.4)</td>
<td>45.0</td>
<td>128.0</td>
</tr>
<tr>
<td>Full Cohort Male ((n = 61, 40.7%))</td>
<td>79.1 (14.0)</td>
<td>53.3</td>
<td>128.0</td>
</tr>
<tr>
<td>Full Cohort Female ((n = 89, 59.3%))</td>
<td>63.9 (11.1)</td>
<td>45.0</td>
<td>95.5</td>
</tr>
<tr>
<td>Lordotic Group 1 ((n = 51))</td>
<td>73.4 (13.0)</td>
<td>49.8</td>
<td>104.4</td>
</tr>
<tr>
<td>Lordotic Group 1 Male ((n = 29, 56.9%))</td>
<td>79.9 (11.0)</td>
<td>53.3</td>
<td>104.4</td>
</tr>
<tr>
<td>Lordotic Group 1 Female ((n = 22, 43.1%))</td>
<td>64.2 (9.6)</td>
<td>49.8</td>
<td>91.7</td>
</tr>
<tr>
<td>Non-Lordotic Group 2 ((n = 99))</td>
<td>68.3 (14.9)</td>
<td>45.0</td>
<td>128.0</td>
</tr>
<tr>
<td>Non-Lordotic Group 2 Male ((n = 32, 32.3%))</td>
<td>78.4 (16.5)</td>
<td>60.9</td>
<td>128.0</td>
</tr>
<tr>
<td>Non-Lordotic Group 2 Female ((n = 67, 67.7%))</td>
<td>63.8 (11.6)</td>
<td>45.0</td>
<td>95.5</td>
</tr>
</tbody>
</table>

\(M = \text{Mean, } SD = \text{Standard Deviation, } n = \text{Number of Participants, Data Presented as } n(\% \text{ of cohort}).\)

In conclusion, the two research groups’ mean mass values differ from each other by 5.1 kg, while the cohort’s mean mass value lies approximately within the centre of the lordotic and non-lordotic groups. Group segregation occurred post inclusion, following radiographic classification. As females predominate groups 2, and typically exhibit less mass than males this would explain the results seen between the lordotic and non-lordotic groups mean mass values. The strict asymptomatic inclusion criteria implemented during this research project was robust enough to negate this small difference in the groups’ mean mass values.
3.6.4 Anthropometric measurements: Blood pressure

Arterial pressure was measured by an Omron IA2™ digital blood pressure monitor (Figure 3.4) and reported in millimetres of mercury (mmHg). O'Brien et al. (2003) and Jhalani et al. (2005) suggested that up to 25% of patients exhibit greater blood pressure measures during clinical evaluation than they do during normal day to day life. This phenomenon is termed “white-coat hypertension”, and examination anxiety is thought to be responsible for this phenomenon. If patients are given the opportunity to relax for five minutes in a private part of the office, their blood pressure tends to normalise and represents their normal pressure more accurately (Elliott, 2007).
Pressure measurements were performed following the completion of the project’s passive documentation, typically requiring a period of 10 minutes. The relaxed participant was seated with their feet flat on the floor. Tight clothing was removed from their upper arms, and the test arm was positioned on a folded towel on the table to permit the cuff to be located level with their heart. The arm was guided through the cuff loop and located with the cuff’s triangular marker on the anterior aspect of the arm proximal to the cubital fossa, over the distal aspect of the brachial artery. Once secured firmly with the velcro strip, the start button was pressed to inflate the cuff and initiate the measurement. Upon completion, the blood pressure displayed on the monitor was recorded. The process was replicated to measure the opposite arm (Bickley & Szilagyi, 2012; El Assaad, Topouchian, & Asmar, 2003).
3.6.4.1 Blood pressure: Results, discussion and conclusion

The participants’ blood pressure measures are presented in Tables 3.13 and 3.14. The upper limit of blood pressure normality is 135/85 mmHg, and all mean blood pressure measures were less than the measure considered normal. The mean blood pressure measure difference between arms, the full cohort, and the two research groups is ≤ 5 mmHg. Male participants exhibited bilateral mean blood pressure measures approximately 10 mmHg higher than the female mean. It is evident that a small number of both male and female participants within this research project exhibited mild hypertension in both systolic and diastolic measures (Table 3.15).

Table 3.13.
Digital Blood Pressure Measures Right Side, Full Cohort and the Two Groups.

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>Blood Pressure M(SD)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Side (mmHg)</td>
<td>Systolic</td>
<td>Diastolic</td>
<td>Systolic</td>
</tr>
<tr>
<td>FC (n = 150)</td>
<td>130 (12.0)</td>
<td>75 (9)</td>
<td>95</td>
</tr>
<tr>
<td>FC Male (n = 61, 40.7%)</td>
<td>136 (9.8)</td>
<td>74 (9)</td>
<td>109</td>
</tr>
<tr>
<td>FC Female (n = 89, 59.3%)</td>
<td>125 (11.7)</td>
<td>76 (8)</td>
<td>95</td>
</tr>
<tr>
<td>L G 1 (n = 51)</td>
<td>132 (12.6)</td>
<td>75 (9.2)</td>
<td>101</td>
</tr>
<tr>
<td>L G 1 Male (n = 29, 56.9%)</td>
<td>137 (9.4)</td>
<td>75 (10.1)</td>
<td>110</td>
</tr>
<tr>
<td>L G 1 Female (n = 22, 43.1%)</td>
<td>125 (13.2)</td>
<td>76 (7.9)</td>
<td>101</td>
</tr>
<tr>
<td>NL G 2 (n = 99)</td>
<td>128 (11.6)</td>
<td>75 (8.2)</td>
<td>95</td>
</tr>
<tr>
<td>NL G 2 Male (n = 32, 32.3%)</td>
<td>134 (10.2)</td>
<td>74 (8.6)</td>
<td>109</td>
</tr>
<tr>
<td>NL G 2 Female (n = 67, 67.7%)</td>
<td>126 (11.2)</td>
<td>76 (8.0)</td>
<td>95</td>
</tr>
</tbody>
</table>

FC = Full Cohort, L = Lordotic, N-L = Non-Lordotic, G = Group, M = Mean, SD = Standard Deviation, n = Number of Participants, Data Presented as n (% of cohort).
Table 3.14.  
Digital Blood Pressure Measures Left Side, Full Cohort and the Two Groups.

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>Blood Pressure M(SD)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left Side (mmHg)</td>
<td>Systolic</td>
<td>Diastolic</td>
</tr>
<tr>
<td>FC (n = 150)</td>
<td>128 (11.3)</td>
<td>101</td>
<td>53</td>
</tr>
<tr>
<td>FC Male (n = 61, 40.7%)</td>
<td>134 (10.7)</td>
<td>103</td>
<td>53</td>
</tr>
<tr>
<td>FC Female (n = 89, 59.3%)</td>
<td>124 (10.1)</td>
<td>101</td>
<td>57</td>
</tr>
<tr>
<td>L G 1 (n = 51)</td>
<td>131 (11.4)</td>
<td>101</td>
<td>58</td>
</tr>
<tr>
<td>L G 1 Male (n = 29, 56.9%)</td>
<td>135 (8.6)</td>
<td>116</td>
<td>58</td>
</tr>
<tr>
<td>L G 1 Female (n = 22, 43.1%)</td>
<td>124 (11.8)</td>
<td>101</td>
<td>62</td>
</tr>
<tr>
<td>N-L G 2 (n = 99)</td>
<td>127 (11.1)</td>
<td>103</td>
<td>53</td>
</tr>
<tr>
<td>N-L G 2 Male (n = 32, 32.3%)</td>
<td>132 (12.3)</td>
<td>103</td>
<td>53</td>
</tr>
<tr>
<td>N-L G 2 Female (n = 67, 67.7%)</td>
<td>124 (9.6)</td>
<td>108</td>
<td>57</td>
</tr>
</tbody>
</table>

FC = Full Cohort, L = Lordotic, N-L = Non-Lordotic, G = Group, M = Mean, SD = Standard Deviation, n = Number of Participants, Data Presented as n (% of cohort).

Table 3.15.  
Ranges for Blood Pressure While Using Digital Blood Pressure Monitors (O’Brien et al., 2003).

<table>
<thead>
<tr>
<th>Hypertension (mmHg)</th>
<th>Daytime</th>
<th>Low</th>
<th>Normal</th>
<th>Borderline</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic</td>
<td>&lt;100</td>
<td>100 - 135</td>
<td>136 - 140</td>
<td>141 - 155</td>
<td>156 - 170</td>
<td>&gt;170</td>
<td></td>
</tr>
<tr>
<td>Diastolic</td>
<td>&lt;65</td>
<td>65 - 85</td>
<td>86 - 90</td>
<td>91 - 100</td>
<td>101 - 110</td>
<td>&gt;110</td>
<td></td>
</tr>
</tbody>
</table>
When considering the age of the participants within this research project (18 to 30 years), hypertension is possible. It is evident that daily systolic blood pressure variability can be as much as 50 - 60 mmHg with asymptomatic participants. However, given that “white-coat hypertension” anxiety could have increased blood pressure by as much as 30 mmHg or more, this may have accounted for the mild hypertension measures recorded (O'Brien et al., 2003). O'Brien et al. (2003) suggests that for differences between arms > 20 mmHg for systolic, or >10 mmHg for diastolic pressure, cardiovascular referral is required to investigate arterial disease. No participant recorded differences in bilateral blood pressure measures of this magnitude. In conclusion, the mean blood pressure measures were within normal limits.

3.6.5 Postural screening: Background rationale

Postural screening is critically important, allowing the examiner to assess the functional alignment of the participant’s MSK system among other criteria. The foundation of any meaningful postural screening protocol is the identification of obvious deviations away from a predominantly neutral, symmetrical MSK alignment pattern (Cipriano, 2010). The initial visualisation process focuses on the general appearance and functional positioning of the body’s appendicular skeleton in relation to its axial skeleton. The body’s regional segments should exhibit an overall structural relationship with one another, allowing the examiner to infer assumptions related to the participant’s postural alignment and possibly any structural pathology (red flags) (Magee, 2014; Watson & Mac Donncha, 2000). It is important to note that by the time the postural screening protocol was conducted, the examiner had reviewed the findings related to the self-reporting and survey documentation. The participant’s passive background screening documentation identified any inherited, traumatic and/or pathological disorders and, allowed participants to be excluded prior to this stage of the PE ($n = 24$).
3.6.5.1 Postural screening: Procedural technique

For this research project, a greater emphasis was placed on the MSK system in comparison to the subcutaneous soft tissues and skin; however, no visual finding was disregarded. To enhance the validity of the postural screening protocol, the barefoot participants wore appropriate fitness-related attire (Schwertner et al., 2016). The participants were instructed to stand and assume a relaxed stationary posture while looking straight ahead, focusing their line of sight on an imaginary level horizon (Dunk, Chung, Compton, & Callaghan, 2004; Watson & Mac Donncha, 2000). The status of the participant’s overall habitually assumed neutral postural was the screening’s initial focus, bearing in mind that the research environment is an unfamiliar situation (Ribeiro et al., 2017).

Figure 3.5. Key anatomical points to consider during postural screening, photographs by Lee Daffin.
A head-to-toe systematic observational approach was undertaken, commencing with the posterior perspective and then continuing around the participant in a 360˚ appraisal that included the right lateral, anterior and left lateral views (Figure 3.5). Upon completion of the initial gross postural appraisal, the examiner directed their attention toward regional alignment attributes in conjunction with the overlying soft tissue characteristics. Anterior and posterior assessment was conducted via a visualised reference line that divided equally the right and left halves of the body, allowing postural contrasting. Screening encompassed, coronal head tilt, shoulder height, vertebral alignment abnormalities, pelvic tilt, excessive valgus and/or varus deviations at the elbow and/or knee joints, foot complex abnormalities, symmetry in limb size, shape, body contours and outlines (Bullock-Saxton, 1993; Magee, 2014; Ribeiro et al., 2017; Schwertner et al., 2016; Watson & Mac Donncha, 2000).

The visualised reference line used during right and left lateral assessment represented the participant’s cranial CoM line of gravity (sagittal vertical axis). The fall of the line of gravity was contrasted against several key points identified in Figure 3.5 including:

- the central point on the lateral aspect of the acromion process.
- the symmetrical bisection of the thorax.
- the fall slightly anterior to the sacroiliac joint.
- the posterior fall at the hip joint through the greater trochanter.
- the point slightly anterior to the centre of the knee.
- the centre of the lateral malleolus (Ribeiro et al., 2017; Schwertner et al., 2016).
At the end of the postural screening protocol, the side of coronal head tilt was recorded to possibly be used in future comparisons with the photogrammetric measures. All visual information was considered while establishing if the participant’s structural alignment resembled a normal asymptomatic participant, and hence permitting inclusion. Following the conclusion of the official postural screening protocol, the physical demeanour of the participant continued to be monitor throughout the duration of the PE process. The researcher made every effort to identify any physical issues that may have constituted an exclusion event.

**3.6.5.2 Postural screening: Results, discussion and conclusion**

A step defect at L4/5 was exhibited by 4 participants with spondylolisthesis, confirmed radiographically in all cases following referral to their general practitioner. The participant’s postural screening side of coronal head tilt data for the full cohort and the two groups is presented in Table 3.16. There is not a precedent within the literature to compare these data against. Objective analysis reveals that during stance, while assuming a relaxed stationary posture looking straight ahead and focusing their line of sight on an imaginary level horizon, participants’ side of coronal head tilt is predominately towards the left-hand side (59.3% of the time). When considering the two groups, the lordotic group exhibits slightly more participants with coronal head tilt to the left-hand side (at 64.7%). The significance of asymptomatic head tilt is not established currently. In conclusion, side of head tilt is not associated with handedness, its neural coordination mechanisms appear to be independent from that associated with upper limbs dominance.
Table 3.16.  
Side of Coronal Head Tilt for the Full Cohort and the Two Groups.

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>Right Head Tilt</th>
<th>Left Head Tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Cohort ((n = 150))</td>
<td>(n = 61) (40.7%)</td>
<td>(n = 89) (59.3%)</td>
</tr>
<tr>
<td>Full Cohort Male ((n = 61, 40.7%))</td>
<td>(n = 26) (42.6%)</td>
<td>(n = 35) (57.4%)</td>
</tr>
<tr>
<td>Full Cohort Female ((n = 89, 59.3%))</td>
<td>(n = 35) (39.3%)</td>
<td>(n = 54) (60.7%)</td>
</tr>
<tr>
<td>L Group 1 ((n = 51))</td>
<td>(n = 18) (39.3%)</td>
<td>(n = 33) (64.7%)</td>
</tr>
<tr>
<td>L Group 1 Male ((n = 29, 56.9%))</td>
<td>(n = 11) (37.9%)</td>
<td>(n = 18) (62.1%)</td>
</tr>
<tr>
<td>L Group 1 Female ((n = 22, 43.1%))</td>
<td>(n = 7) (31.8%)</td>
<td>(n = 15) (68.2%)</td>
</tr>
<tr>
<td>N-L Group 2 ((n = 99))</td>
<td>(n = 43) (43.4%)</td>
<td>(n = 56) (56.7%)</td>
</tr>
<tr>
<td>N-L Group 2 Male ((n = 32, 32.3%))</td>
<td>(n = 14) (43.8%)</td>
<td>(n = 18) (56.2%)</td>
</tr>
<tr>
<td>N-L Group 2 Female ((n = 67, 67.7%))</td>
<td>(n = 29) (43.9%)</td>
<td>(n = 38) (56.7%)</td>
</tr>
</tbody>
</table>

\(L = \text{Lordotic, N-L = Non-Lordotic, } n = \text{Number of Participants, Data Presented as n (% of cohort).}\)

### 3.6.6 Adams forward-bending test: Background rationale

Spinal scoliosis (Idiopathic Scoliosis) is a lateral deviation of the spinal (vertebral) column on the coronal plane, manifesting itself as a complex, three-dimensional spinal malformation. This change in spinal alignment often diminishes the normal sagittal curves, especially the thoracic kyphosis. Adam’s forward-bending test has traditionally been utilised by health practitioners as an effective initial scoliotic screening tool (Choudhry, Ahmad, & Verma, 2016). This scoliotic detection test is not considered a definitive diagnostic tool as an unacceptable number of false negatives transpire (E. M. Clark, Tobias, & Fairbank, 2016; Karachalios et al., 1999). Scoliosis has the propensity to exist as a benign structural abnormality (E. M. Clark et al., 2016), and it is for this reason the test was included within the PE protocol. Adam's forward-bending test is considered the best non-invasive clinical test to evaluate scoliosis (Côté, Kreitz, Cassidy, Dzus, & Martel, 1998). The authors report the following values, 0.92 (95% CI: 0.85-1) sensitivity (LR+ 2.3) and 0.60 (95% CI: 0.47-0.74) specificity (LR- 0.13).
3.6.6.1 Adam’s forward-bending test: Procedural technique

The examiner stood behind the relaxed, erect participant while recalling the degree of postural symmetry observed during the postural screening. The participant was instructed to bend forward at the hips while keeping their knees straight, and then remain stationary when the spine was in a horizontal position. The test is negative if the participant’s spine and thorax remain level from left to right (Figure 3.6); however, if either side is higher, the test is positive for scoliosis. At the end of the screening process, the participants were instructed to stand up (Cipriano, 2010; E. M. Clark et al., 2016; Magee, 2014).

3.6.6.2 Adam’s forward-bending test: Results

Structural scoliotic defects excluded 5 participants from this research project.

Figure 3.6. Adam’s forward-bending test. A. Adolescent male demonstrating the initial starting position of the test (slight right concave thoracolumbar scoliotic curve). B. Negative Adam’s forward-bending test, photographs by Lee Duffin.
3.6.7 Functional squat test: Background rationale

The functional squat test (FST) (Childress’ sign) is a movement screen intended to globally assess lower limb peripheral joint movement patterns. The FST is a provocative measure of function using the participant’s body mass to place incremental biomechanical stress throughout the entire kinetic chain consisting of the hip, knee and ankle joints and their associated musculature. Successful completion of the FST involves coordination of strength and mobility within the lower limbs. The movement quality and symmetrical application is critically appraised when determining test success. As the FST nears the deepest region of the squatting movement, aberrant movement patterns may be exhibited due to limited muscular extensibility and/or weakness, reduced joint mobility and/or stability (hypermobility) and pathological conditions. Painful motion, facial grimacing and joint crepitus can also signify problems in the kinetic chain (Butler, Plisky, Southers, Scoma, & Kiesel, 2010). Childress’ sign represents the most accurate physical test to predict aberrant lower limb motion, particularly meniscal injuries (Pookarnjanamorakot, Korsantirat, & Woratanarat, 2004). The authors report the following values, 0.68 sensitivity (LR+ 1.7) and 0.66 specificity (LR-0.53).

3.6.7.1 Functional squat test: Procedural technique

The participants were instructed to stand with their feet positioned straight ahead at approximately shoulder width apart. The participants were instructed to squat down as deep as they physically could by bending their knees and lowering their buttocks towards their heels, while keeping their heels on the ground and not leaning forward. Each participant was encouraged to allow their thighs to descend beneath the point at which they were parallel to the floor, while attempting to track their knees over their toes. Once the participant reached their lowest point, they were instructed to return to the standing position (Butler et al., 2010; Cliborne et al., 2004).
3.6.7.2 Functional squat test: Results

All participants performed the FST sufficiently, permitting inclusion at this point of the PE.

3.6.8 Modified romberg’s test (eyes open and closed): Background rationale

Sensorimotor integration allows sensory feedback to be processed and transformed into advantageous motor programs (Shadmehr, Smith, & Krakauer, 2010). Romberg’s test investigates coordination within the participant’s proprioceptive system (Magee, 2014). Healthy balance parameters demand the seamless integration of three neurological systems. The visual system allows adjustments to a change in postural positioning, whereas the vestibular and proprioceptive systems provide positional awareness of the head and body in space respectively (Khasnis & Gokula, 2003; Michiels et al., 2013). Crucially, effective balance is sustainable if any two of the three systems contribute sufficient accurate neural information (Khasnis & Gokula, 2003). Romberg’s exploits this balance fact by simply asking the participant to shut their eyes (Khasnis & Gokula, 2003; Magee, 2014).

Removal of visual stimulation prevents the participant adjusting their posture in accordance with possible visual changes within the environment (Bickley & Szilagyi, 2012; Magee, 2014). Greater reliance is consequently transferred onto the proprioceptive and vestibular systems to maintain balance. A loss of motor coordination (ataxia) while the eyes are closed is deemed to be a positive indicator for sensory ataxia. The neurological assumption is that there is a change within the sensory pathways’ (dorsal columns of the spinal cord) ability to provide sufficient information for adequate sensorimotor integration (Khasnis & Gokula, 2003; Magee, 2014). A negative (normal) Romberg’s test occurs in the absence of any excessive postural sway (Khasnis & Gokula, 2003; Magee, 2014), changes in
the position of the arm(s) (Bickley & Szilagyi, 2012), or overbalancing events (McMichael, Vander Bilt, Lavery, Rodriguez, & Ganguli, 2008). A positive (abnormal) Romberg’s test occurs if excessive postural sway is exhibited (Khasnis & Gokula, 2003; Magee, 2014), any alteration in the position of the arm(s) is evident (Bickley & Szilagyi, 2012), or a change in foot position is required to regain postural balance (McMichael et al., 2008).

The standardised Romberg’s test involves allowing the participant’s arms to rest comfortably by their sides (Cipriano, 2010; Khasnis & Gokula, 2003; Magee, 2014). In the evidence based MSK literature no consensus exists concerning the reliability (intra and inter) or validity of the Romberg's test, it is considered qualitative rather than quantitative. It is however, a quick and efficient clinical balance assessment test (McMichael et al., 2008). The authors report the following values, 0.24 sensitivity and 0.89 specificity. It is important to note: a specificity value of 0.89 is advantageous when evaluating asymptomatic participants who are correctly identified as not having a qualitative alteration in balance control.

Modification to the Romberg’s test involves instructing the participant to position their arms so that their glenohumeral joint is flexed to 90° on the sagittal plane, elbows are extended, and forearms are supinated. Placing the arms in this position increases the test’s neural complexity allowing for the evaluation of pronator drift in conjunction with the sensory ataxia (Figure 3.7A). Any downward movement of the arm(s) in conjunction with forearm pronation, elbow and/or finger flexion is indicative of a contralateral lesion in the corticospinal tract (Figure 3.7B) (Bickley & Szilagyi, 2012). Romberg’s test does not test cerebellar ataxia, as increased postural sway occurs with the eyes open in participants with cerebellar dysfunction (Cipriano, 2010). There are numerous neurological disorders responsible for ataxia (Khasnis & Gokula, 2003). Any sign of ataxia, regardless of cause,
resulted in the participant’s exclusion and referral to their medical practitioner for further evaluation.

*Figure 3.7. Modification to the Romberg’s Test incorporating the Pronator Drift Test. A. Starting position. B. Positive pronator drift sign, photographs by Lee Daffin.*

3.6.8.1 *Modified romberg’s test (eyes open and closed): Procedural technique*

The examiner instructed the barefoot participant to stand comfortably with their feet just touching while looking straight ahead (Cipriano, 2010; Khasnis & Gokula, 2003; Magee, 2014). Modification to the Romberg’s test involved instructing the participant to raise their arms up in front of themselves so that they were parallel with the floor, with their palms facing upwards (Bickley & Szilagyi, 2012). The participants stood unsupported with their eyes open in the test position for 30 seconds while the examiner observed the degree sway and/or body movements. If the preliminary phase of the test was completed safely without overbalancing, the participant was advised to close their eyes and remain in this position until the test concluded. Prior to closing their eyes, the participants were instructed to immediately open their eyes if they felt they were going to overbalance and fall while their eyes were closed (Khasnis & Gokula, 2003).
The examiner stood behind the participant with both their arms outstretched on either side of the participant’s thorax in preparation to catch the participant in case an overbalance event was to transpire. The participant was instructed to close their eyes and remain in the test position for 30 seconds. While the participant’s eyes were closed, the examiner assessed the degree of change within their postural sway parameters. Assessment also included the initial direction of sway upon eye closure, alterations in arm placement and evidence of foot movement during overbalancing events. At the end of the testing period, participants were instructed to open their eyes, lower their arms and relax (Khasnis & Gokula, 2003; Magee, 2014; McMichael et al., 2008).

3.6.8.2 *Modified romberg’s test (eyes open and closed): Results*

All participants performed the Modified Romberg’s Test sufficiently, permitting inclusion at this point of the PE.

3.6.9 *Cerebellar finger-to-nose Test: Background rationale*

The cerebellar finger-to-nose test (CFNT) is an established component of the neurological upper limb coordination examination (Feys et al., 2003). The capacity to accomplish smooth, precise and coordinated movements is a functional requirement of any healthy integrated neuromusculoskeletal system. To achieve cohesive coordination involves multiple areas within the CNS including the cerebellum, basal ganglia, dorsal columns and cerebral cortex (Swaine, Lortie, & Gravel, 2005). The CFNT endeavours to identify any deficiencies in the quality of the participant’s movement coordination. Functional motion must be performed smoothly and easily, and if unable to do so, cerebellar impairment is suspected (Cipriano, 2010). Dysmetria is an inability to judge the position (distance) or scale of the intended target, such as the tip of the nose in this case. The decomposition of
movement can be observed as hypermetria - an exaggeration (overshooting), and hypometria - a diminution (undershooting) of the intended target and/or an associated tremor during the test (Schmahmann, Weilburg, & Sherman, 2007).

Two forms of tremor have been classified during the CFNT. A simple small amplitude kinetic tremor is noted from the commencement of the movement through the entire distance to the nose. An intention tremor is a tremor of increased amplitude, noted as the finger approaches to within 5cm of the nose (Feys et al., 2003). Although the CFNT is readily used within both research and clinical settings, no common protocol is recognised as the gold standard (Feys et al., 2003). The authors reported that the interrater reliability for the CFNT across 15 pairs of raters while assessing simple kinetic tremor demonstrated a moderate kappa coefficient 0.49-0.52 however, while assessing intention tremor a substantial kappa coefficient 0.65-0.74 was identified.

3.6.9.1 Cerebellar finger-to-nose test: Procedural technique

The starting position involved the barefoot participant standing with their feet shoulder width apart. Instructions detailed the starting position which involved: bilateral glenohumeral joint abduction to 90°on the frontal plane, and full extension at the elbow joints with the index fingers extended, while the remain finger were flexed to forming a fist. The CFNT procedure was demonstrated in full by the examiner, while positioned directly in front of the participant. A note was made to the participant as to what exactly constituted the tip of the nose and index finger. Alternating arm movements required the non-test arm to remain stationary in the starting position while the opposite (test) arm performed the CFNT. The non-test arm must remain stationary until the test arm has returned to the aforementioned starting position and stopped moving completely (Cipriano, 2010; Feys et al., 2003; Swaine, Desrosiers, Bourbonnais, & Larochelle, 2005).
Participants were instructed to place the tip of their index finger onto the tip of their nose as fast and as precisely as they could manage, and then return their arm back to the starting position. To successfully touch the nose with the tip of the index finger, flexion of the elbow was required. The participant was instructed to begin the test and complete three full cycles once they closed their eyes. A complete cycle involved alternating movements of both the left and right arms (Feys et al., 2003; Swaine, Desrosiers, et al., 2005; Swaine, Lortie, et al., 2005). During the CFNT, the examiner observed the degree of coordination noting the quality of motion achieved by the participant including overshooting, undershooting and any form of limb tremor (Feys et al., 2003; Schmahmann et al., 2007).

3.6.9.2 Cerebellar finger-to-nose test: Results

All participants performed the CFNT sufficiently, permitting inclusion at this point of the PE.

3.6.10 Active shoulder range of motion: Background rationale

A fundamental aspect of any upper body PE is the functional evaluation of the shoulder complex. Appreciation is critical on two distinct levels: (1) its isolated functionality as an independent anatomical structure, and (2) its complex functional inter-relationship with the axial skeleton (Beach & Gordon, 2016; Neumann, 2013). Static and dynamic observations are performed either sitting or standing, and must incorporate multiple perspectives to enhance the development an overall representation of the shoulder complex. Static inspection must visualise both shoulders in their entirety and together, to guarantee rashes, tissue redness, bruising, scaring, muscular atrophy, abnormalities and irregularities are not overlooked. The postural screening protocol assessed the static qualities of the shoulder complex during this PE (Beach & Gordon, 2016; Cipriano, 2010; Neumann, 2013).
The shoulder complex is rightly named as it consists of four joints, three of which are structural synovial joints including the sternoclavicular, acromioclavicular, glenohumeral joints, while the scapulothoracic joint is purely functional in nature. Active shoulder range of motion (aSROM) evaluation protocols must appreciate and incorporate all four joints to be truly valid (Beach & Gordon, 2016; Bickley & Szilagyi, 2012; Magee, 2014; Norkin & White, 2016). Regional interdependence is decisively important during aSROM evaluation due to the complexity of joints constituting the shoulder girdle, both structurally and functionally. This PE incorporated aSROM protocols, as apparent unrelated MSK impairment(s) in distant anatomical regions can cause the primary problem to develop in another isolated region (Wainner et al., 2007). Anatomically, there is a well-defined symptomatic association between the neck and the shoulder complex (Figure 3.8); however, the epidemiological mechanisms responsible for non-specific neck and shoulder pain are not well defined in the general population (Takasawa et al., 2015).

Figure 3.8. The area that neck and shoulder pain is experienced, adapted from (Takasawa et al., 2015).
An elevated occurrence of palpable tenderness (Andersen, Hansen, Mortensen, & Zebis, 2011) and altered motor control (Szeto, Straker, & O'Sullivan, 2005) are observed within the upper fibres of the trapezius when contrasting asymptomatic and symptomatic participants. These distinct physiological differences deeply link the neck and shoulder complex together in an almost inseparable relationship (Andersen et al., 2011). Studies investigating reliability, validity, sensitivity and specificity in relation to aSROM have focused on the test retest accuracy of instruments designed to record the available motion (Hayes, Walton, Szomor, & Murrell, 2001).

### 3.6.10.1 Active shoulder range of motion: Procedural technique

The minimum movements required to validate a dynamic aSROM evaluation are forward flexion, abduction, external rotation, and internal rotation. Passive shoulder ROM is not required to be assessed if aSROM is full and not problematic (Beach & Gordon, 2016). The goal of any purposeful PE is the maximum procurement of constructive evidence whilst performing the protocols in an efficient, systematic manner. To improve movement efficiency and moderate the level of physical stress placed on the participants, both component movements on the given plane will be assessed as a single sequential movement from one terminal end to the other. Flexion and extension are combined to represent sagittal plane motion, abduction and adduction represent coronal plane motion, and transverse plane motion will incorporate internal rotation and external rotation (Bickley & Szilagyi, 2012; Cipriano, 2010; Magee, 2014). As the participants reached their available end ROM in the assessed plane, they were instructed to pause and count to three (Cipriano, 2010; Magee, 2014; Norkin & White, 2016). The authors maintain the examiner has the capacity to move freely around the participants and observe the movement from various orientations if warranted. The participants were instructed to perform this movement only if it was comfortable to do so.
3.6.10.2 Active shoulder range of motion: Flexion and extension

During evaluation of flexion, the examiner instructed the participants to assume a comfortable standing posture with their feet shoulder-width apart and arms relaxed by the sides of their body. The examiner stood in front of the participants and performed the aSROM protocol for flexion while simultaneously instructing the participants to mirror the observed movement at a constant speed without stopping. The protocol for flexion involved the participants raising both their arms simultaneously in front of their body while keeping their elbows straight and forearms in a mid-pronated position (Figure 3.9).

When returning to the starting position, their elbows straight and forearms in a mid-pronated position, the movement continued past the original starting position and progressed to the available end ROM in extension (Figure 3.9). Once they had completed the task, the participants were instructed to return their arms to the starting position and rest comfortably with their arms by their sides. Initially the examiner observed the guided motion from the anterior perspective. The participants were instructed to perform the previous protocol again, without guidance, while the examiner repositioned himself to observe the posterolateral protocol.

The examiner attempted to observe bilateral, pain-free symmetrical aSROM on the sagittal plane, with the desired ranges including $\geq 165^\circ$ of flexion and $\geq 50^\circ$ of extension. Regardless of causation, a positive test result was indicated when the participant was unable to perform the aSROM protocol anywhere along the movement path from one terminal end of range to the other on the sagittal plane. At the terminal end of flexion, the joints of the shoulder complex are in an identical position to that observed during glenohumeral abduction. Compensatory movements may include, but are not limited to, extension, flexion
and lateral flexion of the spinal column, giving the impression of glenohumeral extension. Scapulothoracic adduction (retraction) can also give the appearance of glenohumeral extension (Cipriano, 2010; Magee, 2014; Norkin & White, 2016).

Figure 3.9. Sagittal plane shoulder motion: Flexion (≥ 165°) and Extension (≥ 50°), photograph by Lee Daffin.
3.6.10.3 Active shoulder range of motion: Abduction and adduction

During evaluation of abduction, the examiner and participants were initially positioned as previously described. The examiner performed the aSROM protocol for abduction while simultaneously instructing the participants to mirror the observed movement at a constant speed without stopping. The examiner raised both arms together out to the side of their body while keeping their elbows straight and allowing forearms to supinate from a mid-pronated start until the palms came together at the terminal end ROM in abduction (Figure 3.10). Returning to the starting position, the examiner continued the aSROM movement past the starting position and continued across the front of the body to achieve the available end ROM in adduction (Figure 3.10). Identical terminal end of range instructions were provided (Cipriano, 2010; Magee, 2014; Norkin & White, 2016).

![Figure 3.10](image)

*Figure 3.10. Coronal plane shoulder motion: Abduction (≥ 160°) and Adduction (≥ 50°), photograph by Lee Daffin.*
Once completed, the participants were instructed to return their arms to the starting position and rest comfortably with their arms by their sides. Again, the examiner repositioned himself to observe the posterolateral protocol, while the participants were instructed to perform the previous protocol again. Movement observation involved aSROM on the coronal plane with the desired ranges including \( \geq 160^\circ \) of abduction and \( \geq 50^\circ \) of adduction. Regardless of causation, a positive test result was indicated when the participant was unable to perform the aSROM protocol anywhere along the movement path from one terminal end of range to the other on the coronal plane. Scapulohumeral rhythm commonly displays variability in dynamic functioning due to uncoordinated aberrant stabilisation mechanisms involving either the scapulothoracic or glenohumeral joints in isolation, or more commonly in conjunction with each other. The sternoclavicular and acromioclavicular joints must not be overlooked during aSROM evaluation through abduction and adduction (Cipriano, 2010; Magee, 2014; Norkin & White, 2016).

### 3.6.10.4 Active shoulder range of motion: Internal and external rotation

During evaluation of external rotation, the examiner and participants were initially positioned as previously described; however, the initial starting position for the arms was different to that previously described for the sagittal and coronal planes as they now resided on the transverse plane. The examiner performed the aSROM protocol for external rotation, while simultaneously instructing the participants to mirror the observed movement at a constant speed without stopping. The examiner abducted their glenohumeral joints to 90\(^\circ\), while flexing their elbows to 90\(^\circ\) and pronating their forearms. Beginning from this starting position (Figure 3.11A), the examiner turned their forearm backward lifting their hands posterosuperiorly to reach the terminal end ROM in external rotation where the palms faced anteriorly (Figure 3.11B) (Cipriano, 2010; Magee, 2014; Norkin & White, 2016).
Returning to the starting position, the examiner continued the aSROM movement past the starting position and continued into internal rotation (Figure 3.12A). The forearm moved in a posteroinferior direction to reach the terminal end of range whereby the palms were facing posteriorly (Figure 3.12B). Identical terminal end of range instructions were provided (Cipriano, 2010; Magee, 2014; Norkin & White, 2016).

*Figure 3.11. Transverse plane shoulder motion external rotation. A. Starting position (0°). B. The terminal end range of motion for external rotation (≥ 90°), photographs by Lee Daffin.*

Again, the examiner repositioned himself to observe the posterolateral protocol, while the participants were instructed to perform the previous protocol again. Movement observation involved aSROM on the transverse plane with the desired ranges including ≥ 90° of external rotation and ≥ 70° of internal rotation. Regardless of causation, a positive test result was indicated when the participant was unable to perform the aSROM protocol anywhere along the movement path from one terminal end of range to the other on the coronal plane (Cipriano, 2010; Magee, 2014; Norkin & White, 2016).
The transverse plane aSROM protocol chosen to evaluate external rotation and internal rotation involving the glenohumeral joints being abducted to 90° as opposed to a neutral postural position. Internal and external rotation performed with the glenohumeral joints in neutral incorporates a varying degree of scapulothoracic joint motion being incorporated and recorded in the observed aSROM ranges, comprising scapulothoracic abduction (protraction) during internal rotation and adduction (retraction) during external rotation. Internal rotation measures evaluated with 90° of glenohumeral abduction displayed greater accuracy. Regardless of causation, a positive test result was indicated when the participant was unable to perform the aSROM protocol anywhere along the movement path from one terminal end of range to the other on the transverse plane (Cipriano, 2010; Magee, 2014; Norkin & White, 2016).

*Figure 3.12. Transverse plane shoulder motion internal rotation. A. Starting position (0°). B. The terminal end range of motion for internal rotation (≥ 70°), photographs by Lee Daffin.*

### 3.6.10.5 Active shoulder range of motion: Results and conclusion

Two participants were excluded from the research project due to not achieving an acceptable ROM either (1) unilaterally or (1) bilaterally. In conclusion, all participants demonstrated the capacity to adequately perform unencumbered aSROM protocols.
3.6.11 Active cervical range of motion: Background rationale

During clinical, research and rehabilitative assessment of the cervical spine, an integral component is the active cervical range of motion (aCROM) measurement (Hoving et al., 2005; Williams, McCarthy, Chorti, Cooke, & Gates, 2010). As a diagnostic indicator, aCROM is capable of distinguishing between asymptomatic participants and those with persistent whiplash-associated disorders (Dall’Alba, Sterling, Treleaven, Edwards, & Jull, 2001). Rehabilitative domains have embraced aCROM as a fundamental assessment tool to evaluate treatment success (Hoving et al., 2005; Kubas et al., 2017; Strimpakos, 2011).

Current research applications include identifying JPS errors during cervical repositioning tasks within asymptomatic populations displaying altered cervical alignment, namely photogrammetrically determined FHP (Yong et al., 2016). Additionally, researchers have identified that aCROM movement speed influences measures (Strimpakos, 2011), while age has a considerable negative influence on aCROM, despite sex not affecting aCROM measures (Swinkels & Swinkels-Meewisse, 2014).

Currently, no officially recognised standardised protocol or instrumentation used for assessing aCROM is recommended within the literature (Cupon & Jahn, 2003; Prushansky & Dvir, 2008; Strimpakos, 2011); however, the American Medical Association (AMA) Guides to the Evaluation of Permanent Impairment stipulate several key methodological processes aimed at standardising aCROM measures. The AMA published “The Practical Guide to Range of Motion Assessment” in an effort to further standardise the aCROM methodologies by specifying 12 identifiable points that reduce the probability of executing common errors regardless of the instrumentation (Cupon & Jahn, 2003). It is advocated that regardless of the instrument used, a full methodological description is vital to allow critical evaluation and clinical reproducibility (Jordan, 2000).
Radiographic evaluation is considered by some researchers to represent the gold standard when definitively assessing aCROM (Cupon & Jahn, 2003; Kubas et al., 2017; Prushansky & Dvir, 2008); however, Hoving et al. (2005) indicated radiographic reproducibility is questionable. Regardless of its merits, radiography has several clinical limitations due to the health impacts associated with ionizing radiation. The technique is costly, and its test re-test inadequacies are evident during daily practice (Kubas et al., 2017). Traditional clinical evaluation of aCROM has been by visual estimation or instrumentation such as a tape measures, goniometers and/or inclinometers (Kubas et al., 2017; Swinkels & Swinkels-Meewisse, 2014). Dual digital inclinometers have demonstrated moderate to excellent intra- and interrater reliability, together with coexisting validity (Hoving et al., 2005; Kubas et al., 2017; Tousignant et al., 2001). Intrarater reliability for aCROM measured with a dual digital inclinometer have reported the following values, 0.96 (95% CI: 0.93-0.98) flexion and extension, 0.93 (95% CI: 0.86-0.97) lateral flexion and 0.96 (95% CI: 0.91-0.98) rotation while, the following interrater reliability values have been reported, 0.95 (95% CI: 0.90-0.98), 0.89 (95% CI: 0.77-0.94) and 0.95 (95% CI: 0.90-0.98), respectively (Hoving et al., 2005).

There are three dominant dual digital inclinometers cited within the literature. They are the AcuMar™ (Lafayette Instrument, Lagatette, IN, USA), the Cybex EDI-320™ (Cybex International, Inc. Medway, MA) and the JTECH™ (JTECH Medical, Salt Lake City, UT, USA). It has been suggested that such an instrument must not be too cost inhibitive, otherwise clinicians will not procure one and will then rely on less accurate means of measurement. Importantly, the measurement instrument must be agreeable with the participant and comprise a level of technological complexity that does not overwhelm the clinician (Jordan, 2000). The AcuMar™ dual digital inclinometer was recently used to
identify a significant negative correlation between the CVA and JPS errors in the sagittal planes, aCROM measures of flexion and extension (Yong et al., 2016). It was decided that the AcuMar™ dual digital inclinometer would be acquired and used during this research project due to the positive results confirmed within the literature.

### 3.6.11.1 Active cervical range of motion: Procedural technique

The AcuMar™ dual digital inclinometer (Figure 3.13) was used during all trials to measure the aCROM on three planes involving the six primary motions of flexion and extension (sagittal plane), left and right lateral flexion (coronal plane), and left and right rotation (transverse plane) (Dall’Alba et al., 2001; Prushansky & Dvir, 2008). The equipment used during the aCROM protocol include one standardised four-legged metal framed chair upholstered in fabric with a lower back backrest. This chair was used to record the sagittal and coronal planes measures, while its orientation and position remained identical during all trials. A standard portable vinyl upholstered padded plinth was used to record the transverse plane measures, while its orientation and position remained identical during all trials (Hoving et al., 2005). A plinth was used during transverse plane trials as gravity was required for the inclinometer to function precisely. The AcuMar™ digital inclinometer protocol for supine cervical rotation measurement on the transverse plane does not require the use of the companion unit; the primary unit operates in isolation while measuring the aCROM (Cupon & Jahn, 2003; Hoving et al., 2005).
Prior to commencement of the aCROM protocol, the instrument’s properties and the testing protocol was explained in detail (Cupon & Jahn, 2003). The participants were informed that the AcuMar™ digital inclinometer consisted of two parts that operated together to measure the movement of the neck while seated, and the single primary unit worked in isolation while lying on the plinth. Also, one inclinometer was situated at the bottom of the participant’s neck on top of an anatomical landmark (C7 spinous process) while the other was situated on top (vertex) of the head. Once seated, the participants were asked to place their lower back firmly and comfortably into the seat’s backrest while assuming a comfortable, natural, non-slouched position. The seated test posture consisted of their bare feet positioned flat on the floor facing forward with their ankles, knees and hips approximately at 90°, shoulders relaxed while looking straight ahead with their eyes open and hands pronated and resting on each upper thigh. The participants were informed that following the seated measurements they would be required to lie on their back on the plinth to allow cervical rotation to be measured (Hoving et al., 2005).
Physical and psychological aCROM preparation was provided in the form of a warm-up/trial performed while seated on the chair and lying supine on the plinth. It is considered warm-up movements enhance measurement precision and reproducibility, therefore, once positioned, the participants were informed that they would be initially guided through the movement. Guided motion provides valuable sensory feedback as to what is expected during the aCROM protocol. Once the examiner was satisfied with the participant’s movement, the participants were instructed to perform the movements unassisted once in either direction (Cupon & Jahn, 2003; Dall’Alba et al., 2001; Hoving et al., 2005; Strimpakos, 2011).

During the performance of the unassisted warm-up movements, participants were instructed to memorise the initial starting position and attempt to replicate that exact position when returning from the end of the individual movement (Yong et al., 2016). Due to the repetitive nature of the testing procedures the following instructions and protocols were performed in each plane and will be detailed as follows. The primary unit was zeroed (0˚) prior to measuring the motion on the given plane. The participants were informed that each movement, for example flexion, is referred to as a half-cycle, and each half-cycle movement would be performed three times, and replicating the original starting position when ending the movement was critical as ideally each movement should start from the same position following the previous maximal half-cycle movement. At the point of maximal motion, the participant paused, and the examiner depressed the hold button and measured the half-cycle movement from the initial starting position. Once the six planar half-cycles were completed, the examiner recorded the six measures. Participants were encouraged to perform a maximal movement at a constant speed while attempting to limit any additional motion in the trunk or body (Hoving et al., 2005; Strimpakos, 2011; Yong et al., 2016).
Preparing the participants was critical, as a complex interplay exists during cervical motion due to the orientation of the cervical facet joints; this inherent natural anatomical occurrence increases the difficulty when measuring aCROM. The resultant coupled movements allow additional out-of-primary plane motions to occur (Hoving et al., 2005; Williams et al., 2010). Within asymptomatic participants, coupled movements abide by identifiable patterns that are characterised by slight inter-individual variations, therefore attempting to limit coupled movements is essential to achieving accurate measures (Cupon & Jahn, 2003; Prushansky & Dvir, 2008). Once seated and/or lying and warmed up as described, the aCROM test protocol was as follows. The cited references for the seated aCROM protocols will be combined and follow the left/right lateral flexion protocol descriptions as all the references were used to describe both protocols.

3.6.11.2 Active cervical range of motion: Flexion and extension

The examiner stood behind the participant and placed the primary measurement unit on the vertex of the head, orientated sagittally. The companion unit was placed on a pre-marked dot on the tip of the spinous process of C7. The participant was instructed to move their head forward at a constant speed as if moving their chin to their chest without moving their trunk on the chair. At the point of maximal cervical flexion (Figure 3.14A), the participant paused, and the motion was recorded. Once recorded, the participant was instructed to return to the initial start position and stop.
Figure 3.14. Sagittal plane active cervical motion. A. Flexion (45° to 50°). B. Extension (80° or >), photographs by Lee Daffin.

Following flexion, the participant was instructed to move their head backwards at a constant speed as if looking up towards the ceiling without moving their trunk. At the point of maximal cervical extension (Figure 3.14B), the participant paused, and the examiner depressed the hold button and measured the movement from the initial start position. Once recorded the participant was instructed to return to the start position and stop.

3.6.11.3 Active cervical range of motion: Right and left lateral flexion

The described protocol is identical for both left and right lateral flexion. The examiner stood behind the participant and placed the primary unit on the vertex of the head, orientated coronally. The companion unit was placed on a pre-marked dot on the tip of the spinous process of C7. The participant was instructed to move their head to the side at a constant speed as if moving their ear towards their shoulder. This movement was to be performed without moving their trunk on the chair or elevating their shoulder towards the ear.
At the point of maximal lateral flexion (Figure 3.15), the participant paused, and the examiner depressed the hold button and measured the movement from the initial starting position. Once recorded the participant was instructed to return to the start position and stop. The ipsilateral lateral flexion movement was repeated to both the left and right side (Cupon & Jahn, 2003; Dall’Alba et al., 2001; Hoving et al., 2005; Nitschke, Nattrass, Disler, Chou, & Ooi, 1999; Williams et al., 2010; Yong et al., 2016).

![Figure 3.15. Coronal plane active cervical motion. A. Left Lateral Flexion (40° or >). B. Right Lateral Flexion (40° or >), photographs by Lee Daffin.](image)

### 3.6.11.4 Active cervical range of motion: Right and left rotation

The described protocol is identical for both left and right supine rotation. Once the participant was lying on their back with their head close to the end of the plinth and warmed up, the test protocol was as follows. The examiner sat on a chair close to and facing the participant’s head. The primary unit was positioned on the apex of the participant’s forehead. The participants were instructed to turn (rotate) their head to the side at a constant speed as if looking over their shoulder.
During rotation movement, the participants were encouraged to limit the coupled movement of lateral flexion. The test was repeated if excessive lateral flexion accompanied rotation. At the point of maximal rotation, the ROM was recorded, and the participants were then instructed to return to the start position and stop (Figure 3.16). The ipsilateral rotation movement was repeated to both the left and right side (Hoving et al., 2005; Kubas et al., 2017).

3.6.11.5 Active cervical range of motion: Results

The results for the aCROM are presented within the following five tables (Table 3.17 to 3.21). Pain and guarding elicited during end range right rotation and right lateral flexion resulted in the exclusion of 1 participant from the research project.

Figure 3.16. Transverse plane supine active cervical motion. A. Left Rotation (80° or >). B. Right Rotation (80° or >), photographs by Lee Daffin.
Table 3.17.  
Active Cervical Range of Motion: Mean and Standard Deviation for the Full Cohort and the two Groups, Including All Male and Female Results.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Sagittal</th>
<th>Coronal</th>
<th>Transverse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td>L Lat Flex</td>
</tr>
<tr>
<td>FC (n = 150)</td>
<td>51.5° (8.5)</td>
<td>65.0° (7.6)</td>
<td>44.9° (7.1)</td>
</tr>
<tr>
<td>FC M (n = 61, 40.7%)</td>
<td>51.3° (7.7)</td>
<td>61.6° (12.0)</td>
<td>45.0° (7.0)</td>
</tr>
<tr>
<td>FC F (n = 89, 59.3%)</td>
<td>51.6° (9.0)</td>
<td>67.3° (10.6)</td>
<td>44.9° (7.1)</td>
</tr>
<tr>
<td>L G 1 (n = 51)</td>
<td>53.0° (8.6)</td>
<td>60.0° (11.0)</td>
<td>43.0° (7.0)</td>
</tr>
<tr>
<td>L G 1 M (n = 29, 56.9%)</td>
<td>53.4° (8.0)</td>
<td>58.1° (11.4)</td>
<td>45.1° (7.2)</td>
</tr>
<tr>
<td>L G 1 F (n = 22, 43.1%)</td>
<td>52.5° (9.7)</td>
<td>62.6° (10.1)</td>
<td>40.1° (5.6)</td>
</tr>
<tr>
<td>NL G 2 (n = 99)</td>
<td>50.7° (8.3)</td>
<td>67.5° (10.7)</td>
<td>45.9° (6.9)</td>
</tr>
<tr>
<td>NL G 2 M (n = 32, 32.3%)</td>
<td>49.2° (6.9)</td>
<td>64.9° (11.8)</td>
<td>45.0° (7.0)</td>
</tr>
<tr>
<td>NL G 2 F (n = 67, 67.7%)</td>
<td>51.4° (8.9)</td>
<td>68.7° (10.0)</td>
<td>46.3° (6.9)</td>
</tr>
</tbody>
</table>

FC = Full Cohort, L = Lordotic, N-L = Non-Lordotic, L = Left, R = Right, Lat Flex = Lateral Flexion, Rot = Rotation, G = Group, M = Male, F = Female, n = Number of Participants, Data Presented as n (% of cohort).

Table 3.18.  
Active Cervical Range of Motion: Mean Planar Motion, Differences Between the Full Cohort and the Two Groups, and Group to Group Difference.

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>Sagittal</th>
<th>Coronal</th>
<th>Transverse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td>L Lat Flex</td>
</tr>
<tr>
<td>FC (n = 150)</td>
<td>51.5°</td>
<td>65.0°</td>
<td>44.9°</td>
</tr>
<tr>
<td>L G 1 (n = 51)</td>
<td>53.0°</td>
<td>60.0°</td>
<td>43.0°</td>
</tr>
<tr>
<td>N-L G 2 (n = 99)</td>
<td>50.7°</td>
<td>67.5°</td>
<td>45.9°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>G 1 / G 2</th>
<th>G 1 / G 2</th>
<th>G 1 / G 2</th>
<th>G 1 / G 2</th>
<th>G 1 / G 2</th>
<th>G 1 / G 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC to G Difference</td>
<td>1.5° / 0.8°</td>
<td>5.0° / 2.5°</td>
<td>1.9° / 1.0°</td>
<td>1.6° / 0.9°</td>
<td>0.2° / 0.0°</td>
<td>0.1° / 0.0°</td>
</tr>
<tr>
<td>G 1 to G 2 Difference</td>
<td>2.3°</td>
<td>7.5°</td>
<td>2.9°</td>
<td>2.5°</td>
<td>0.2°</td>
<td>0.1°</td>
</tr>
</tbody>
</table>

FC = Full Cohort, L = Lordotic, N-L = Non-Lordotic, L = Left, R = Right, Lat Flex = Lateral Flexion, G = Group, n = Number of Participants.
Table 3.19. Active Cervical Range of Motion: Combined Planar Motion for the Full Cohort and the Two Groups, Including All Male and Female Results.

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>Sagittal Combined</th>
<th>Coronal Combined</th>
<th>Transverse Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td>L Lat Flex</td>
</tr>
<tr>
<td>FC (n = 150)</td>
<td>116.5</td>
<td>87.4</td>
<td>156.4</td>
</tr>
<tr>
<td>FC M (n = 61, 40.7%)</td>
<td>112.9</td>
<td>87.6</td>
<td>160.8</td>
</tr>
<tr>
<td>FC F (n = 89, 59.3%)</td>
<td>118.9</td>
<td>87.4</td>
<td>153.4</td>
</tr>
<tr>
<td>L G 1 (n = 51)</td>
<td>113.0</td>
<td>83.9</td>
<td>156.5</td>
</tr>
<tr>
<td>L G 1 M (n = 29, 56.9%)</td>
<td>111.5</td>
<td>86.7</td>
<td>160.4</td>
</tr>
<tr>
<td>L G 1 F (n = 22, 43.1%)</td>
<td>115.1</td>
<td>80.0</td>
<td>150.7</td>
</tr>
<tr>
<td>N-L G 2 (n = 99)</td>
<td>118.2</td>
<td>89.3</td>
<td>156.4</td>
</tr>
<tr>
<td>N-L G 2 M (n = 32, 32.3%)</td>
<td>114.1</td>
<td>88.5</td>
<td>161.2</td>
</tr>
<tr>
<td>N-L G 2 F (n = 67, 67.7%)</td>
<td>120.1</td>
<td>89.6</td>
<td>154.2</td>
</tr>
</tbody>
</table>

**FC = Full Cohort, L = Lordotic, N-L = Non-Lordotic, L = Left, R = Right, Lat Flex = Lateral Flexion, G = Group, M = Male, F = Female, n = Number of Participants, Data Presented as n (%) of cohort.**

### 3.6.11.6 Active cervical range of motion: Discussion

The use of aCROM is extensive within all domains that either investigate or attempt to rehabilitate the cervical spine. Establishing an asymptomatic cohort was the primary focus of the PE, and it is for this reason that an aCROM protocol was performed during the PE to allow comparison and contrasting of the aCROM results with normative aCROM data within the literature. Unfortunately, no officially recognised gold standard exists concerning either the aCROM protocol or instrumentation used to assess the motion. The AMA stipulates several points that reduce the probability of executing common errors during aCROM protocols, while this research project adheres strictly to all the relevant points.
Table 3.20.  
*Active Cervical Range of Motion Minimum, Maximum and Range for the Full Cohort and the Two Groups, Including All Male and Female Results.*

<table>
<thead>
<tr>
<th>Research Participants</th>
<th>Sagittal</th>
<th>Coronal</th>
<th>Transverse</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum / Maximum</td>
<td>Minimum / Maximum</td>
<td>Minimum / Maximum</td>
</tr>
<tr>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td>L Lat Flex</td>
</tr>
<tr>
<td>FC (n = 150)</td>
<td>31.7 / 75.3</td>
<td>35.7 / 96.3</td>
<td>30.7 / 63.7</td>
</tr>
<tr>
<td>FC Range</td>
<td>43.6</td>
<td>60.6</td>
<td>33.0</td>
</tr>
<tr>
<td>FC M (n = 61, 40.7%)</td>
<td>36.0 / 72.3</td>
<td>39.7 / 94.0</td>
<td>34.0 / 62.7</td>
</tr>
<tr>
<td>FC M Range</td>
<td>36.3</td>
<td>54.3</td>
<td>28.7</td>
</tr>
<tr>
<td>FC F (n = 89, 59.3%)</td>
<td>31.7 / 75.3</td>
<td>35.7 / 96.3</td>
<td>30.7 / 63.7</td>
</tr>
<tr>
<td>FC F Range</td>
<td>43.6</td>
<td>60.6</td>
<td>33.0</td>
</tr>
<tr>
<td>L G 1 (n = 51)</td>
<td>36.0 / 72.3</td>
<td>35.7 / 94.0</td>
<td>30.7 / 57.3</td>
</tr>
<tr>
<td>L G 1 Range</td>
<td>36.3</td>
<td>58.3</td>
<td>26.6</td>
</tr>
<tr>
<td>L G 1 M (n = 29, 56.9%)</td>
<td>39.0 / 72.3</td>
<td>39.7 / 94.0</td>
<td>34.0 / 57.3</td>
</tr>
<tr>
<td>L G 1 M Range</td>
<td>33.3</td>
<td>54.3</td>
<td>23.3</td>
</tr>
<tr>
<td>L G 1 F (n = 22, 43.1%)</td>
<td>36.0 / 67.7</td>
<td>35.7 / 82.7</td>
<td>30.7 / 53.3</td>
</tr>
<tr>
<td>L G 1 F Range</td>
<td>31.7</td>
<td>47.0</td>
<td>22.6</td>
</tr>
<tr>
<td>L G 2 (n = 99)</td>
<td>31.7 / 75.3</td>
<td>39.7 / 96.3</td>
<td>30.7 / 63.7</td>
</tr>
<tr>
<td>L G 2 Range</td>
<td>43.6</td>
<td>56.6</td>
<td>33.0</td>
</tr>
<tr>
<td>L G 2 M (n = 32, 32.3%)</td>
<td>36.0 / 65.0</td>
<td>39.7 / 88.3</td>
<td>35.3 / 62.7</td>
</tr>
<tr>
<td>L G 2 M Range</td>
<td>29.0</td>
<td>48.6</td>
<td>27.4</td>
</tr>
<tr>
<td>L G 2 F (n = 67, 67.7%)</td>
<td>31.7 / 75.3</td>
<td>44.7 / 96.3</td>
<td>30.7 / 63.7</td>
</tr>
<tr>
<td>L G 2 F Range</td>
<td>43.6</td>
<td>51.6</td>
<td>33.0</td>
</tr>
</tbody>
</table>

FC = Full Cohort, L = Lordotic, N-L = Non-Lordotic, L = Left, R = Right, Lat Flex = Lateral Flexion, G = Group, M = Male, F = Female, n = Number of Participants, Data Presented as n (% of cohort).
Motion within the craniocervical region is highly variable. Neumann (2013) suggests from the anatomical position, this region can obtain in its normative state approximately 45° to 50° of flexion, 75° to 80° of extension and exhibit 120° to 130° of combined motion. Approximately 35° to 40° is achievable during lateral flexion bilaterally, with 70° to 80° of combined motion, and 65° to 75° of rotation achievable with 130° to 150° of combined motion available (Table 3.17 and 3.19) (Neumann, 2013). Table 3.17 to 3.19 demonstrate that this cohort’s aCROM findings align with the Neumann (2013) suggested values except the mean extension value is 65°, being 10° less that the Neumann (2013) value of 75°. J. Chen, Solinger, Poncet, and Lantz (1999) published a meta-analysis of normative aCROM data from participants aged 20 to 50 across nine different measurement technologies (Table 3.1). J. Chen et al. (1999) indicated that mean dual digital inclinometer measures were shown to be 51° of flexion, 70° of extension and 121° of combined motion, while 44° of right and 41° of left lateral flexion with 85° of combined motion were reported. J. Chen et al. (1999) did not report any dual digital inclinometer measures for rotation.
Comparisons between this cohort’s aCROM findings for mean extension and J. Chen et al. (1999) findings indicate the difference has now halved to $5^\circ$ less than the J. Chen et al. (1999) figure of $70^\circ$, while J. Chen et al. (1999) stated extension exhibited the largest between-technique difference of movement measure being $44^\circ$. J. Chen et al. (1999) indicated the gold standard normative radiographic aCROM measures to be $50^\circ \pm 14^\circ$ of flexion and $67^\circ \pm 4^\circ$ of extension, with a combined measure of $121 \pm 16^\circ$; when compared to this cohort’s aCROM findings they are almost an exact comparison (Table 3.17 to 3.19). Takasaki, Hall, Kaneko, Ikemoto, and Jull (2011) confirmed via radiographic analysis of asymptomatic young participants that the upper and lower segments of the cervical spine respond differently during extension. Initiating extension in a protracted position produces more extension at C1-2 and less at C6-7, with the reverse occurring when extending from the retraction position.

Bogduk and Mercer (2000) and Neumann (2013) both described the variance in the upper and lower regions of the cervical spine with respect to their anatomy and biomechanics. The two regions have distinct arthrokinematic qualities, the variance due to the atlas, axis and the C2-3 inter-vertebral junction constituting the upper region, and the remainder of the cervical spine constituting the lower region (C3 - C7). Ferrario, Sforza, Serrao, Grassi, and Mossi (2002) remarked that quantitative motion analysis of the cervical spine is difficult due to the associated out-of-plane motion resulting from these distinct arthrokinematic qualities. Therefore, it is advantageous to eliminate all external movement and standardise the initial starting aCROM posture as much as possible (Ferrario et al., 2002).
J. Chen et al. (1999) commented that true validity is not possible within the aCROM domain due to the number of measurement technologies used and protocols engaged in determining aCROM measures. Regardless of this comment, both Hoving et al. (2005) and Prushansky, Deryi, and Jabarreen (2010) support the digital inclinometer as an effective instrument for assessing aCROM. Prushansky et al. (2010) reported aCROM measurements generated by a digital inclinometer are reproducible and valid for recording seated sagittal and coronal plane motions in healthy participants. Rotation results can vary due to the supine testing position adopted by the participants. J. Chen et al. (1999) and Prushansky et al. (2010) agreed that the digital inclinometer is recommended due to its ease of operation for tester and participant alike, for its cost effectiveness and portability, making it ideally suited for clinical practice.

The full cohort’s mean aCROM data indicates that comparisons made between male and female mean aCROM data and the full cohort indicated overall similarities existed, and neither sex overshadowed the other across all the assessed movements (Table 3.17). When participants were grouped according to their cervical alignment characteristic, it was interesting to note that males in the lordotic Group 1 exhibited larger mean aCROM measures across all movements except for extension. Whereas in the non-lordotic Group 2 males and females, they exhibited equal proportionality between all the assessed movements (Table 3.17). Contrasting the difference between the means of the two groups and the full cohort’s means indicates that extension exhibited the largest mean difference, being 5° (lordotic Group 1), while right rotation exhibited the smallest mean difference, being 0.0°. The largest mean difference between the two groups was 7.5° for extension, and the lowest was 0.1° for right rotation. The mean difference for the 12 movements representing the 6 assessed movement across both groups was an average of 1.3° (Table 3.17 and 3.18). The aCROM
range for all movements was considerably larger, and in most of the measures the range was larger than the minimum score for that measure (Table 3.20 and 3.21). Contrasting the cohort’s aCROM measures with the J. Chen et al. (1999) mean aCROM normative dataset across nine technologies indicates similarities exist in all movement parameters (Table 3.22).

**Table 3.22.**

*Meta-analysis: Mean Normative Data Set for the Active Cervical Range of Motion Derived Across Nine Technologies (J. Chen et al., 1999).*

<table>
<thead>
<tr>
<th></th>
<th>Sagittal Mean (SD)</th>
<th>Coronal Mean (SD)</th>
<th>Transverse Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flexion</td>
<td>Extension</td>
<td>L Lat Flex</td>
</tr>
<tr>
<td>Overall Mean Data</td>
<td>52 (7)</td>
<td>71 (5)</td>
<td>42 (2)</td>
</tr>
<tr>
<td>Combined Movements</td>
<td>126 (12)</td>
<td>86 (5)</td>
<td>151 (23)</td>
</tr>
</tbody>
</table>

L = Left, R = Right, Lat Flex = Lateral Flexion, SD = Standard Deviation.

### 3.6.11.7 Active cervical range of motion: Conclusion

In conclusion, if the mean aCROM measures for the full cohort are considered, they are comparable to those identified in the literature. The cohort’s mean extension measure of 65° is 10° less than that reported by Neumann (2013) at 75°, and 5° less than the mean extension measures identified by J. Chen et al. (1999) at 70°. When compared with the gold standard, being radiography, the cohort’s mean extension measure of 65° is 2° less than the reported radiographic measure of 67°. The cohort’s mean measures are comparable to the J. Chen et al. (1999) mean aCROM normative dataset across nine technologies. The aCROM measures of this cohort are comparable to those measures reported by previous normative research cohorts. This cohort represents an asymptomatic cohort in all aspects when considering the aCROM measures.
3.6.12 Passive cervical range of motion: Background rationale

Identification of possible pathological conditions involving synovial joints and their overlying connective tissues is achieved by the application of examiner-controlled passive overpressure applied across the participant’s joint structures at the end range of the joint(s). Passive overpressure allows the examiner to potentially discriminate between physiological (active) end range and anatomical (passive) end range (Magee, 2014). Specific directional passive overpressure across the joint, once it has reached its active end range, allows the examiner to produce more joint excursion, therefore passive motion is uniquely positioned to assess motion that is unable to be achieved physiologically (Jordan, 2000; Strimpakos, 2011). Overpressure is only applied when the examiner’s intuition and experience determines that the motion produced is free from restrictions, full, and, importantly, not inducing a painful stimulus which is detrimental to wellbeing (Magee, 2014). Strimpakos (2011) identified inter-examiner overpressure variability while measuring passive cervical range of motion (pCROM) as a key limiting factor while administering the protocol. Studies investigating reliability, validity, sensitivity and specificity in relation to pCROM have focused on the test retest accuracy of the examiners while performing passive measurements using a variety of instruments (J. Chen et al., 1999). This research project relied on pCROM to assess the end feel quality of the cervical spine following the application of overpressure.

Normal cervical end feel following overpressure should initially exhibit a soft tissue stretching sensation followed by a gradual increase in joint stiffness until a cessation in motion is felt under the examiner’s hands (Salo, Hakkinen, Kautiainen, & Ylinen, 2009). The application of passive overpressure is primarily applied to the cervical spine to estimate the quality of end feel during flexion, extension, lateral flexion, and axial rotation movements (Salo et al., 2009). The anatomy and vascular physiology of the cervical spine can predispose the participant to potential risks during examination protocols. Overpressure during rotation,
lateral flexion and extension has the potential to elicit additional compensatory (coupled) motion with the capacity to compress and compromise the integrity of the vertebral arteries. Compression can restrict blood flow to the brain in addition to irritating delicate neural structures (Magee, 2014).

Performing pCROM within both clinician and research settings provides several benefits: the technical level of complexity is low, expensive equipment is not required, and procedural protocols are relatively simple to follow (Jordan, 2000). The benefits are credible; however, pCROM requires many years of clinical practice to perfect the skills required to interpret what is being felt under a clinician’s hands. In terms of establishing which clinical option has greater significance during a cervical diagnostic procedure, Strimpakos (2011) believes pCROM provides greater diagnostic reliability than aCROM. NSNP participants exhibit quantifiable reductions in both aCROM and pCROM measures compared to asymptomatic participants.

Clinical diagnostic procedures including static palpation, pCROM and aCROM protocols have the diagnostic capacity to distinguish NSNP from asymptomatic participants. This diagnostic capacity is achievable due to the consistencies, or inconsistencies, in the quality of the integumentary systems’ texture coupled with the characteristics observed and felt during both aCROM and pCROM respectfully (Rutledge et al., 2013). These crucial pCROM qualities and outcomes are the impetus for the inclusion of the pCROM protocol in this PE.
3.6.12.1 Passive cervical range of motion: Procedural technique

Equipment used during the pCROM protocol included the identically positioned chair as previously described for aCROM protocol. Following the successful completion of the aCROM protocol, the participant returned from the plinth and resumed the identical seated testing posture described previously for the seated aCROM protocol. This position was maintained for the entire pCROM protocol, as right and left rotation are assessed seated, and not supine, as dictated in the aCROM protocol (Magee, 2014; Rutledge et al., 2013).

The pCROM protocol required the examiner to stand near the posterior aspect of the seated participant’s craniocervical region. The examiner’s position permitted the observation of any aberrant cervical motion related to the passive limitations created at the anatomical end range of the movement, while applying overpressure to the gross cervical spine. The pCROM protocol was not instigated to reassess aCROM, instead the examination’s primary focus was the quality of the craniocervical region’s connective tissues at their end range, as passive overpressure at the anatomical end range of joint excursion should not elicit restriction or a painful stimulus (Magee, 2014; Rutledge et al., 2013).

3.6.12.2 Passive cervical range of motion: Flexion and extension

The examiner placed his left hand on the participant’s proximal posterior thoracic spine while the contralateral hand was placed midline on the parietal region of the cranium. The participants were instructed to slowly move their head forward at a constant speed as if moving their chin to their chest without moving their trunk on the chair. The examiner passively directed the participant’s head towards the end-point of maximal cervical flexion (60° or greater) until the examiner sensed an end range palpable change within the tissues’ tension. At this point, a small magnitude of passive overpressure was applied in the direction
of further flexion to subjectively ascertain the connective tissues inherent qualities (Magee, 2014; Rutledge et al., 2013).

At the end range, the overpressure was relaxed and reapplied several times to diagnose the tissues’ resistance qualities while receiving proprioceptive feedback from the participant’s cervical spine. The area within the cervical region’s intervertebral foramen increased by up to 30% during flexion. Once passive evaluation was completed, the participant’s head was directed into extension to return the participant’s head to the initial, neutral starting position. A positive test while evaluating pCROM through flexion may include, but not be limited to, nausea, sensory paraesthesia, severe pain and cord signs (Magee, 2014; Rutledge et al., 2013).

The examiner’s left hand remained on the participant’s proximal posterior thoracic spine while the contralateral hand was relocated to the midline frontal region of the cranium. The participants were instructed to slowly move their head backwards at a constant speed as if looking up towards the ceiling without moving their trunk. The examiner passively directed the participant’s head towards the end-point of maximal cervical extension (75° or greater) until the examiner sensed an end range palpable change within the tissues’ tension (Magee, 2014; Rutledge et al., 2013).

An identical protocol was performed as described during flexion, except passive overpressure was applied into further extension. Normally, during extension when overpressure is applied, the plane of the forehead lies approximately parallel to the transverse plane. Once completed, the participant’s head was directed into flexion to return the participant’s head to the initial, neutral starting position A positive test while evaluating
pCROM through extension may include, but not be limited to, a blocked reduced CROM into extension, sensory alterations within the upper or lower limbs, a sense of vertigo suggesting vertebrobasilar insufficiencies and/or cord compression (Magee, 2014; Rutledge et al., 2013).

3.6.12.3  *Passive cervical range of motion: Right and left lateral flexion*

During evaluation of left lateral flexion, the examiner placed his left hand on the lateral aspect of the right shoulder girdle over the acromion process while the right hand was placed on the right tempoparietal region of the cranium, with the fingers orientated superiorly, as closely aligned to the cranium’s coronal plane as possible. The participants were instructed to slowly move their head at a constant speed to the left, as if moving their ear towards the shoulder. The examiner passively directed the participant’s head towards the end-point of maximal left lateral flexion (45° or greater) until the examiner sensed an end range palpable change within the tissues’ tension. Simultaneously, while passive overpressure was being applied, the examiner scrutinised the participant’s left shoulder girdle to ensure it remained stationary and did not move superiorly towards the left ear. Due to the coupled movements associated with left lateral flexion, the examiner ensured compensatory movements were considered carefully, particularly left rotation and flexion (Magee, 2014; Rutledge et al., 2013).

It is common when evaluating cervical lateral flexion to observe rotation and flexion, therefore re-testing was performed if compensatory motion occurred during the lateral flexion pCROM protocol. The end-point of maximal left lateral flexion is the point at which compensatory mechanisms do not significantly influence the observed lateral flexion motion. An identical protocol was performed as described during flexion, except overpressure was produced into further left lateral flexion. Once completed, the participant’s head was directed
into right lateral flexion to return the participant’s head to the initial, neutral starting position. A positive test while evaluating pCROM through left lateral flexion could include, but is not limited to, conditions identified previously during flexion and extension (Magee, 2014; Rutledge et al., 2013).

During evaluation of right lateral flexion, the examiner placed their right hand on the lateral aspect of the left shoulder girdle over the acromion process while the left hand was placed on the left temporoparietal region of the cranium, with the fingers orientated superiorly as closely aligned to the cranium’s coronal plane as possible. An identical pCROM protocol as described during left lateral flexion was followed while undertaking similar observational procedures (Magee, 2014; Rutledge et al., 2013).

3.6.12.4 Passive cervical range of motion: Right and left rotation

During evaluation of left rotation, the examiner re-positioned their body to the right posterolateral aspect of the participant, while facing in a left anterolateral direction. The examiner placed their right hand’s thenar eminence on the right angle of mandible with their fingers directed superiorly and placed on the anterolateral aspect of the right frontal bone. The contralateral hand’s thenar eminence was placed on the left angle of mandible with the fingers orientated superiorly, abducted and placed on the lateral aspect of the cranium. The fingers of the contralateral hand were flexed, therefore the palm lay over the left ear without touching or applying pressure to it. The participants were instructed to slowly move and turn their head at a constant speed to the left as if looking over their shoulder. The examiner passively directed the participant’s head towards the end-point of maximal left rotation (80° or greater) until the examiner sensed an end range palpable change within the tissues’ tension (Magee, 2014; Rutledge et al., 2013).
Simultaneously, the examiner scrutinised the movement closely to ensure the left shoulder girdle remained stationary and did not move towards the left ear. Due to the coupled movements associated with rotation, the examiner ensured compensatory movements were considered carefully, particularly left lateral flexion and flexion. Participants should possess the capacity to perform rotation in isolation without exhibiting excessive compensatory lateral flexion. Compensatory movements are intra-individualised and may not essentially occur in the same direction as lateral flexion during rotation. These movements are typically produced because of a reduced physiological capacity to effectively rotate the cervical spine (Magee, 2014; Rutledge et al., 2013).

The end-point of maximal left rotation is the point at which compensatory mechanisms do not significantly influence the observed left rotational motion. An identical protocol was performed as described during flexion, except overpressure was produced into further left rotation. Once completed, the participant’s head was directed into right rotation to return the participant’s head to the initial, neutral starting position. A positive test while evaluating pCROM through left rotation could include, but is not limited to, conditions identified previously during flexion, extension and lateral flexion (Rutledge et al. 2013 and Magee 2014).

During evaluation of right rotation, the examiner re-positioned their body to the left posterolateral aspect of the participants, while facing in a right anterolateral direction. The examiner relocated their hands to the identical position previously described, but reversed. An identical pCROM protocol as described during left rotation and was followed while undertaking similar observational procedures (Rutledge et al. 2013 and Magee 2014).
3.6.12.5 Passive cervical range of motion: Results and conclusion

The pCROM protocol resulted in the exclusion of two participants from the research project due to pain and guarding elicited during end range overpressure testing into extension and lateral flexion, respectively. One participant was excluded for excessive guarding during pCROM testing into extension, while the other participant was excluded due to pain elicited during pCROM testing into left lateral flexion. In conclusion, all participants included in this research project demonstrated ideal pCROM testing protocols signifying no musculoskeletal problem that warranted exclusion.

3.6.13 Manual isometric muscle testing: Background rationale

Muscular contractions are an objective physical characteristic with the capacity to be assessed and critically evaluated to determine deficits. Although muscular contractions are an objective characteristic, obtaining reliable and valid data while assessing muscular strength has proven to be a challenging endeavour in both clinical and research environments. There are several factors that can influence the overall results during assessment including strength characteristics, endurance/fatigue, body position, age and pain (N. Strimpakos, 2011). The extensive variety of measurement devices in conjunction with no standardised methodological protocols or recommendations concerning the reporting of results has unfortunately confounded the range of strength results’ reports within the literature (Dvir & Prushansky, 2008; N. Strimpakos, 2011). Both Dvir and Prushansky (2008) and N. Strimpakos (2011) have expressed concerns over the lack of cohesive guidance in the literature which they feel has attributed to, and is responsible for, preventing the establishment of reliable normative reference standards within the muscular strength assessment domain.
Kubas et al. (2017) attempted to establish a standardised methodological protocol that could be followed by researchers to reduce the probability of inconsistent methodologies negatively influencing results. Standardisation involved incorporating written scripts, photographs and improved examiner training techniques to enhance the participant’s body placement, the protocols, instructions and timing. Kubas et al.’s (2017) recommendations were implemented and/or adapted to enable improved standardisation of the manual isometric muscle testing (MIMT) protocols used during this PE.

Presently, no clear consensus exists amongst researchers or clinicians concerning the correlation between pain, its intensity and muscular strength values. Chiu and Sing (2002) and Ylinen, Salo, Nykänen, Kautiainen, and Hämäläinen (2004) determined pain was associated with a reduction in muscular strength production, whereas De Loose et al. (2009) reported no significant differences in cervical muscular strength was observed between asymptomatic and symptomatic male pilots. Males within all age ranges reported greater isometric neck strength, approximately 20% to 70% greater, in comparison to female participants (Salo, Ylinen, Malkia, Kautiainen, & Hämäläinen, 2006). No significant correlation within either sex has been identified between anthropometric measurements and isometric neck strength (Chiu, Lam, & Hedley, 2002). Part 2, of a systematic critical review by N. Strimpakos (2011) suggests that clinical assessment of cervical pain through isometric strength testing is not valid and only weakly associated with both pre and post treatment testing. However, this author also indicates no consensus exists within this area as recent research has concluded isometric strength has a strong association with cervical pain. Researchers agree no evidence exists indicating severe undesirable effects have taken place within muscles of the cervical spine in asymptomatic participants following maximum MIMT (N. Strimpakos, 2011).
MIMT is a clinical mainstay with several key functional aspects contributing to this situation, the complexity level is low, the application is straightforward, expensive equipment is not required, the MIMT protocol is time effective, and minimal-to-no costs are associated with its application (Cipriano, 2010; Dvir & Prushansky, 2008; Magee, 2014). Although MIMT is a mainstay, it is reported to exhibit low reliability (de Koning, van den Heuvel, Staal, Smits-Engelsman, & Hendriks, 2008; Dvir & Prushansky, 2008). Studies investigating reliability, validity, sensitivity and specificity in relation to MIMT have focused on the test retest accuracy of instruments designed to record isometric strength measures (de Koning et al., 2008; Dvir & Prushansky, 2008). In terms of MIMT within an asymptomatic population reproducibility is considered doubtful (de Koning et al., 2008). Regardless of the reported low reliability within the literature, MIMT is an important aspect of a comprehensive PE; therefore, MIMT was implemented and performed following the completion of both the aCROM and pCROM protocols. MIMT was primarily incorporated into this PE to identify neuromusculoskeletal dysfunction and exclude participant demonstrating this dysfunction from the research project.

3.6.13.1 Manual isometric muscle testing: Procedural technique

Equipment used during the MIMT protocol included the identically positioned chair used during both the aCROM and pCROM protocols and previously described in the aCROM protocol. Participants assumed the identical test position as described for the seated aCROM protocol, positioning their lower back firmly and comfortably into the seat’s backrest. The participants maintained a neutral head and neck position for the entire MIMT protocol, while the examiner stood centrally and posteriorly near the seated participants. The assumed examiner-participant position implemented during the MIMT protocol enhanced kinaesthetic awareness, and allowed improved subjective perception related to any exhibited aberrant kinematics (Cipriano, 2010; Kubas et al., 2017; Magee, 2014).
The MIMT protocol was instigated to assess neuromusculoskeletal integrity involving the cervical spine in all three planes. The movements of flexion, extension, bilateral lateral flexion, and bilateral axial rotation was assessed though the application of sub-maximal isometric contractions. Sub-maximal isometric contractions were preferred to maximal contraction for two key reasons: (1) participant safety, and (2) there is minimal-to-no change in the body’s position during the MIMT protocol. A satisfactory result during the MIMT protocol involved a decisive neutral sub-maximal isometric contraction being performed by the participants in all movement directions. MIMT scoring in this PE was recorded as “Normal”, “Weakness” or “Pain”. Participants were exclusion when MIMT elicited a painful stimulus or aberrant kinematics (Cipriano, 2010; Kubas et al., 2017; Magee, 2014).

3.6.13.2  Manual isometric muscle testing: Flexion and extension

During evaluation of flexion, the examiner placed his left forearm across the participant’s posterior shoulder girdles from left to right, with his left hand cupping the right acromion process. The examiner placed his right hand on the midline of the cranium’s frontal bone with the finger orientated horizontally and directed to the left. The participants were instructed “Don’t let me move your head”, as this allowed a safe, slowly and progressive increase in the magnitude of muscular exertion required to be resisted, while controlling the tests directionality. Equally matched exertion restrained any physical motion with the participants developing a flexion force to counter the examiner’s extension force. Following a satisfactory sub-maximal contraction, the examiner slowly reduced their level of exertion until the participant’s craniocervical region was stationary and self-supported in the pre-test neutral position. A positive test while evaluating MIMT through flexion could include, but was not limited to, severe pain, sensory paraesthesia, muscular weakness and physical apprehension (Cipriano, 2010; Kubas et al., 2017; Magee, 2014).
During evaluation of extension, the examiner’s left forearm remained in the identical position previously described for flexion. The examiner placed his right hand on the midline of the cranium’s occipital bone with his finger orientated superiorly on the sagittal plane. Identical instructions were provided and followed as previously described for flexion. The participants developed an extension force to counter the examiner’s flexion force (Cipriano, 2010; Kubas et al., 2017; Magee, 2014). Exact comparisons between extension and flexion are unable to be performed as a greater magnitude of cervical extension exertion should be evident due to the larger muscle mass located posteriorly to the medial-to-lateral axis of the neck (Dvir & Prushansky, 2008; Hamilton & Gatherer, 2014; Strimpakos, 2011). A positive test while evaluating extension is like that described for cervical flexion (Cipriano, 2010; Kubas et al., 2017; Magee, 2014).

### 3.6.13.3 Manual isometric muscle testing: Lateral flexion

During evaluation of left lateral flexion, the examiner placed his right forearm across the participant’s posterior shoulder girdles from right to left, with his right hand cupping the left acromion process. The examiner placed his left hand on the skull’s temporoparietal region with the finger orientated superiorly in line with the coronal plane. Identical instructions were provided and followed as previously described for flexion. The participants developed a left lateral flexion force to counter the examiner’s right lateral flexion force. A positive test while evaluating left lateral flexion is like that described for cervical flexion (Cipriano, 2010; Kubas et al., 2017; Magee, 2014).
During evaluation of right lateral flexion, the examiner placed his left forearm across the participant’s posterior shoulder girdles from left to right with his left hand cupping the right acromion process. The examiner placed his right hand on the cranium’s temporoparietal region with the finger orientated superiorly in line with the coronal plane. Identical instructions were provided and followed as previously described for flexion. The participants developed a right lateral flexion force to counter the examiner’s left lateral flexion force (Cipriano, 2010; Kubas et al., 2017; Magee, 2014). Comparisons between left and right lateral flexion on the coronal plane can be performed. The muscular structures located on either side of the anterior-to-posterior axis should be symmetrical, therefore similar magnitudes of muscular exertion should be produced (Dvir & Prushansky, 2008; Hamilton & Gatherer, 2014; Strimpakos, 2011). A positive test while evaluating right lateral flexion is like that described for cervical flexion (Cipriano, 2010; Kubas et al., 2017; Magee, 2014).

3.6.13.4 Manual isometric muscle testing: Right and left rotation

During evaluation of left rotation, the examiner placed both right and left hands bilaterally on the participant’s ipsilateral temporoparietal regions of the cranium with the fingers orientated horizontally and directed anteriorly towards the frontal bone. The examiner’s proximal forearms rested bilaterally on the participant’s posterior shoulder girdles, enhancing the participant’s stability. Identical instructions were provided and followed as previously described for flexion. Participants developed a left rotational force to counter the examiner’s right rotational force. A positive test while evaluating left rotation is like that described for cervical flexion (Cipriano, 2010; Kubas et al., 2017; Magee, 2014).
During evaluation of right rotation, the examiner maintained a bilateral hand and proximal forearm contact identical to that described for left rotation. Identical instructions were provided and followed as previously described for flexion. Participants developed a right rotational force to counter the examiner’s left rotational force (Cipriano, 2010; Kubas et al., 2017; Magee, 2014). Comparisons between left and right rotation on the transverse plane can be performed. The muscular structures used to produce left and right rotational force around the vertical axis should be symmetrical, therefore similar magnitudes of muscular exertion should be produced (Dvir & Prushansky, 2008; Hamilton & Gatherer, 2014; Strimpakos, 2011). A positive test while evaluating right rotation is like that describe for cervical flexion (Cipriano, 2010; Kubas et al., 2017; Magee, 2014).

3.6.13.5 Manual isometric muscle testing: Results and conclusion

MIMT protocols did not exclude any participants from this research project. In conclusion, all participants demonstrated the capacity to adequately match the external force applied to their craniocervical region without simulating deleterious outcomes.
3.6.14 Valsalva’s manoeuvre: Background rationale

The Valsalva manoeuvre is a subjective test which has the capacity to generate a multitude of profound physiological changes within the body. The Valsalva manoeuvre increases intrathecal pressure around the entire spinal cord. This mechanism allows the clinician to compromise possible underlying neurological cord lesions or injuries and/or pathological space occupying lesions, thus assisting and enhancing the overall diagnostic procedure. The physiological changes established by the Valsalva manoeuvre assist clinicians in detecting radicular or neuropathic pain within the cervical spine. The increase in intrathecal pressure can exacerbate nerve root impingement created due to soft tissue (intervertebral disc) or bony (osteoinductive) compression within the spinal canal or intervertebral foramen (Cipriano, 2010; Haldar et al., 2016; Magee, 2014). The Valsalva manoeuvre was evaluated for its ability identify participants with cervical radiculopathy, the following values were reported, 0.22 (95% CI: 0.03-0.41) sensitivity (LR+ 3.5) and 0.94 (95% CI: 0.88-1) specificity (LR- 0.83) (Wainner et al., 2003). It is important to note: a specificity value of 94% is advantageous when evaluating asymptomatic participants who are correctly identified as not having cervical radiculopathy.

3.6.14.1 Valsalva’s manoeuvre: Procedural technique

During the Valsalva manoeuvre, the examiner instructs the seated participants to take a very deep breath, hold that breath in for 2 to 3 seconds and bear down as if moving their bowels and defecating, while attempting to exhale. The manoeuvre is essentially forced expiration without allowing the glottis to open after full inspiration has occurred. In conjunction with a closed mouth, participants were instructed to pinch their nose to prevent air escaping from their upper respiratory tract if required. The protocol was performed with due diligence as participants may become dizzy, nauseous and/or faint either during or
shortly after concluding the protocol because of diminished blood perfusion to the brain. Regardless of causation, a positive test result was indicated when the participant was unable to perform the protocol. Clinical signs may include, but are not limited to, the elicitation of pain regardless of its severity, sensory dermatomal paraesthesia and physical apprehension (Cipriano, 2010; Haldar et al., 2016; Magee, 2014; Wainner et al., 2003).

3.6.14.2 Valsalva’s manoeuvre: Results, discussion and conclusion

The Valsalva manoeuvre did not exclude any participants from this research project. In conclusion, all participants demonstrated the capacity to adequately perform the Valsalva manoeuvre without simulating deleterious outcomes.

3.6.15 Neutral distraction test: Background rationale

The neutral distraction test is an orthopaedic stress test that distracts the cranium superiorly while the incumbent mass of the body prevents the distal aspect of the cervical spine moving in the same direction as the cranium. The overall intension of the protocol is to place tension across the soft tissues and holding elements of the cervical spine through vertical translation. It is commonly acknowledged that a small degree of normal vertical translation occurs during the application of the distraction force. During the application of the distractive force the structures stretched include: the integument, cervical muscles, ligaments, joint capsules, intervertebral discs and vascular structures.

A positive test response occurs if considerable structural separation ≥ 2 mm takes place during the application of the distraction force, pain is elicited during the protocol possibly indicating muscular strain, muscular spasm, ligamentous spraining, discal lesions, upper cervical spine joint dysfunction and/or facet capsulitis (Cipriano, 2010; Magee, 2014;
Osmotherly, Rivett, & Rowe, 2012). Osmotherly et al. (2012) measured the magnitude of
distraction occurring during the neutral distraction test and concluded the level of change is in
line with current clinical beliefs regarding what is occurring in a normal test response. The
neutral distraction test is highly specific when evaluating radicular and neurological pain, it
also correlates positively with radiological signs (Viikari-Juntura, Porras, & Laasonen, 1989).
The authors report the following values, 1.0 sensitivity for neurologic and radiologic signs
and 0.26 specificity for radicular signs, 0.32 for neurologic signs, 0.40 for radiologic signs
and 0.43 for neurologic and radiologic signs. Alternatively, the following values have been
reported, 0.44 (95% CI: 0.21-0.67) sensitivity (LR+ 4.4) and 0.90 (95% CI: 0.82-0.98)
specificity (LR- 0.62) and a kappa coefficient 0.88 (Wainner et al., 2003).

3.6.15.1 Neutral distraction test: Procedural technique

During the neutral distraction test, the examiner instructs the seated participants to
remain as relaxed as possible. The examiner places the midpoint between the thenar and
hypothenar eminences of both hands over the participant’s mastoid processes. The fingers
were orientated superiorly, cupping the posterior aspect of the cranium, while the thumbs rest
posteriorly on the occipital bone. The application of the superiorly directed distractive force
is initiated progressively by the examiner, which removes the compressive force exerted on
the participant’s head and the effect of gravity (Cipriano, 2010; Magee, 2014).

The examiner instructed the participants to immediately inform the examiner if
anything is felt that does not feel right. This protocol is performed with the utmost of care due
to the sensitivities of the structures located within the cervical region. The examiner
continually monitored the participants from the instant the distractive force was applied with
Figure 3.17 indicating distractive force not hand positioning. In the event of a positive
finding, the force is progressively removed to reduce the possibility of inducing further trauma to the structures through the rapid release of the distractive force. Regardless of causation, a positive test result was indicated when the participant was unable to accommodate the physical application of this protocol. Clinical signs may include, but are not limited to, the elicitation of localised cervical pain regardless of its severity and physical apprehension (Cipriano, 2010; Magee, 2014).

Figure 3.17. Neutral distraction test, photograph by Lee Daffin.

3.6.15.2 Neutral distraction test: Results, discussion and conclusion

The neutral distraction test did not exclude any participants from this research project. In conclusion, all participants demonstrated the capacity to tolerate the progressive application of the superiorly orientated distractive force and its subsequent release without simulating deleterious outcomes.
3.6.16 Foraminal compression testing: Background rationale

Cervical radiculopathy is a pathological condition related to a regional nerve root, with pain experienced unilaterally and/or bilaterally in the arm(s), representing the dermatomal distribution corresponding to the specific nerve root (Thoomes et al., 2018; Wainner et al., 2003). It has an annual incidence rate of 63.5 and 107.3 per 100,000 for females and males respectively (Ghasemi et al., 2013). Typically, a cervical IVD protrusion or sequestration is responsible; however, alternative mechanisms of causation are possible including any space-occupying lesion (Wainner et al., 2003) or osseous degeneration such as uncovertebral osteophytes that encroach into the intervertebral foramen resulting in a stenotic event (Hartman, 2014; Taylor, Twomey, & Levander, 2000). The resultant encroachment into the intervertebral foramen by a foreign body results in nerve root inflammation, impingement, or both (Hartman, 2014; Taylor et al., 2000; Wainner et al., 2003).

Takasaki et al. (2009) radiographically investigated the cervical foraminal cross-sectional area in supine participants in both neutral and provocative foraminal compression test postures. Supine participants were placed in positions of extension, ipsilateral lateral flexion and rotation, followed by the application of approximately 7 kilograms of axial compressive force being applied to the participant’s cranium. Takasaki et al. (2009) determined a physiological reduction of approximately 30% was observed in the foraminal cross-sectional area when compared to the control (neutral) position (Figure 3.18). This research project refrains from using eponyms to describe individual foraminal compression tests such as Spurling’s test, instead descriptive movements are used to perform the test described, as considerable procedural variability has been described under this test eponym (Shah & Rajshekhar, 2004; Thoomes et al., 2018).
The specific sequencing of the protocols within this PE was precisely coordinated to reduce the physical stress on participants to allow the highest quality relevant physical information to assist in validating the inclusion or exclusion criteria. During the foraminal compression test protocol, a sequential clustering of the compression tests was performed to increase diagnostic accuracy (Thoomes et al., 2018). The seated compression tests were conducted in the following order: neutral (axial), flexion, extension, and concluded with the maximal foraminal compression test. These tests provoke, or reduce, mechanical deformation on the nerve roots by either increasing or decreasing the intervertebral foramens diameter in addition to distracting the nerve roots and increasing intrathecal pressure (Takasaki et al., 2009).

These tests have the potential to induce participant discomfort, therefore the sequencing has taken into consideration this potential and was performed in a progressive procedural format that built on each provocative potential. Neutral (axial) compression testing compromises the intervertebral foramen in a stable neutral craniocervical position,
consequently, if pain is evoked during this test, further testing can be discontinued. Flexion compression testing alters the necks alignment but increases the intervertebral foramens diameter, and a similar protocol can be pursued if pain is evoked. Extension compression testing compromises the intervertebral foramen even further than the two previous tests, whereas the maximal foraminal compression test involving cervical extension combined with ipsilateral lateral flexion and rotation reduces the diameter of the intervertebral foramen to the greatest extent possible. The sequencing order was chosen for participant safety, ease of application and the enhancement of the diagnostic accuracy.

The clinical diagnosis of cervical radiculopathy remains the primary focus of provocative foraminal compression testing (FCT), but, unfortunately, an accepted standardised diagnostic criterion has not been established involving this condition (Wainner et al., 2003). As a single clinical examination protocol, FCT has demonstrated high estimates for both sensitivity and specificity when evaluating cervical radiculopathy (Ghasemi et al., 2013; Shah & Rajshekhar, 2004; Wainner et al., 2003). Thoomes et al. (2018) reported FCT (cervical extension combined with ipsilateral rotation) values of 0.98 (95% CI: 0.92-0.99) sensitivity and 0.89 (95% CI: 0.77-0.96) specificity. Alternatively, the following values have been reported for FCT (ipsilateral lateral flexion), 0.50 (95% CI: 0.27-0.73) sensitivity (LR+ 3.5) and 0.86 (95% CI: 0.77-0.94) specificity (LR- 0.58) and FCT (cervical extension combined with ipsilateral lateral flexion and rotation), 0.50 (95% CI: 0.27-0.73) sensitivity (LR+ 1.9) and 0.74 (95% CI: 0.63-0.85) specificity LR- 0.58) (Wainner et al., 2003). Lemeunier et al. (2017) cautiously suggested the validity of these tests are not robustly established as yet; however, preliminary indications advocate the use of a foraminal compression test involving extension and rotation when evaluating patients with neck pain.
3.6.16.1 Foraminal compression testing: Procedural technique

During the foraminal compression testing, the examiner instructs the seated participant to remain as relaxed as possible. The examiner placed both right and left hands bilaterally on the participant’s ipsilateral parietal regions of the cranium, with the fingers orientated superiorly and the fingertips just touching over the mid-sagittal plane of the cranium. The examiner’s proximal forearms rested bilaterally on the participant’s posterior shoulder girdles, enhancing the participant’s stability. The application of the axial compressive overpressure on the neutral craniovertebral posture was initiated progressively by the examiner until a level of overpressure was exerted that convince the examiner no symptomatic structures were likely to be present. The level overpressure exerted by the examiner was as consistent as physically possible given the subjective nature of this form of physical test. Once satisfactorily completed, the axial compressive overpressure was progressively released. The examiner maintained the exact hand contact and passively flexed the participant’s craniovertebral structures into a fully flexed position until the anatomical end range was felt. The application of the axial compressive overpressure was again initiated progressively by the examiner onto the flexed cervical spine. Once satisfactorily completed the fully flexed compressive overpressure was progressively released (Cipriano, 2010; Magee, 2014).
Figure 3.19. Foraminal compression testing. 1. Lateral flexion. 2. Axial compressive overpressure, photograph by Lee Daffin.

The examiner maintained the exact hand contacts and passively extended the participants craniovertebral structures from the flexed position into full extension until the anatomical end range was felt. The application of the extension compressive overpressure was again initiated progressively by the examiner onto the extended cervical spine. Once satisfactorily completed the extension compressive overpressure was progressively released and the craniovertebral structures were maintained in the extended position while passive ipsilateral lateral flexion and rotation were combined with the extended position until the anatomical end range is felt. The application of the multiplanar compressive overpressure was initiated progressively by the examiner onto the extended ipsilateral lateral flexed and rotated cervical spine (Figure 3.19). Once satisfactorily completed, the multiplanar compressive overpressure was progressively released, and this exact process is then re-performed on the contralateral side (Cipriano, 2010; Magee, 2014; Wainner et al., 2003).
Regardless of causation, a positive test result was indicated when the participant was unable to accommodate the physical application of any part of this protocol. Clinical signs are very specific for radiculopathy, including paraesthesia and/or numbness within dermatomal distributions located over the anterior thorax, shoulder girdles, arms, hands or fingers (Rainville et al., 2017). The elicitation of physical apprehension or localised cervical pain regardless of its severity does not constitute a positive test for radiculopathy (Magee, 2014); however, it would still constitute exclusion with this research project.

### 3.6.16.2 Foraminal compression testing: Results, discussion and conclusion

The FCT did not exclude any participants from this research project. These four sequenced tests were applied in a progressive nature to the participants, and in doing so, participants were effectively screened for the possibility of any foreign structures within their intervertebral foramen. The component motions of cervical extension, ipsilateral lateral flexion and rotation were shown by Takasaki et al. (2009) to reduce the foraminal cross-sectional area by approximately 30%. Foraminal compression tests on occasions only apply extension and rotation; however, findings by Takasaki et al. (2009) encouraged the application of ipsilateral lateral flexion in combination with extension and rotation during the maximal foraminal compression test protocol. The combination of these three movements ensured that the intervertebral foramen area would be decreased sufficiently.

Although FCT is clinically intended to identify radiculopathy, the elicitation of any negative symptomatic changes was considered as an exclusion event. In conclusion, all participants demonstrated the capacity to tolerate the progressive application of the axial compressive overpressure and its subsequent release without simulating deleterious outcomes.
3.6.17 Neuromusculoskeletal physical examination: Exclusion results

The PE was a fundamental component of this research project’s strict asymptomatic selection criteria. Exclusion was the default decision if any observation was in question. Throughout the course of this research project, the PE conducted in Session 1 excluded 14 potential participants. The participant exclusion rationale is outlined in Table 3.23, and the success of the PE excluding these potential participants is a testament to the strict asymptomatic selection criteria adhered to during Session 1 of this research project.

Table 3.23.
Neuromusculoskeletal Physical Examination Exclusion Rationale.

<table>
<thead>
<tr>
<th>Number</th>
<th>Exclusion Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Structural idiopathic scoliotic defects</td>
</tr>
<tr>
<td>4</td>
<td>Spondylolisthesis with an associate step defect at L4/5</td>
</tr>
<tr>
<td>2</td>
<td>Grossly restricted active shoulder range of motion</td>
</tr>
<tr>
<td>1</td>
<td>Elicitation of pain and guarding during active cervical range of motion</td>
</tr>
<tr>
<td>1</td>
<td>Restricted and guarded extension during passive cervical range of motion</td>
</tr>
<tr>
<td>1</td>
<td>Elicitation of pain during passive cervical range of motion</td>
</tr>
<tr>
<td>14</td>
<td>Total number of participants excluded from the research project</td>
</tr>
</tbody>
</table>
3.7 Answering the Secondary Research Question

3.7.1 Secondary research question

- Are the current published physical examination eligibility instruments used to include or exclude participants effective, when establishing an asymptomatic research sample to investigate the cervical spine?

Chapter 3 has delineated in precise detail the protocols commonly used and widely accepted within the current body of knowledge relating to asymptomatic selection criterion. At the end of every section and/or protocol within Chapter 3, an asymptomatic rationale was presented indicating the reasoning that allowed asymptomatic inclusion and/or exclusion.

Where possible, the results of this research project’s eligibility instruments were compared with normative data to validate this research project sample’s asymptomatic status. Several passive and active eligibility instruments were identified and accepted as valid tools to select asymptomatic participants.

Standardised surveys were designated as a passive research tool and include the Medical Outcomes Study 36-item short-form and the NDI which are extensively used to identify asymptomatic participants. A project-specific self-report questionnaire referred to as The PSQ was an additional passive instrument specifically developed for this research project from methodological criteria published in the postural control domain. This research project also implemented an active mechanism to assist in determining each participant’s asymptomatic status.
A project-specific, neuromusculoskeletal PE was developed through consultation with several MSK practitioners, and investigations into the relevant literature associated with this domain were conducted. In answering the secondary research question associated within this chapter, it is clear two distinct eligibility instruments are commonly implemented when establishing an asymptomatic cervical spine research cohort - passive and active instruments. The standardised passive surveys are shown to be reliable and valid when assessing a participant’s status. This research project was able to exclude six participants though the implementation of the NDI and 18 participants using the project-specific PSQ.

A neuromusculoskeletal PE is considered an active eligibility instrument and is implemented by many research projects to assist in the establishment of an asymptomatic cervical spine research cohort. The active protocols assembled within the PE are shown to be reliable, and for the most part valid; however, the establishment of validity for some protocols is still contentious, but the protocols appear to be moving closer towards validity as additional research is conducted and literature published. This research project was able to exclude 14 participants though the implementation of the PE.

In conclusion, this research project identified passive and active eligibility instruments published in domain appropriate literature. These instruments were then assembled into a cohesive sequential structure that every successful participant completed to be included in this strict asymptomatic cohort. These instruments were able to exclude 32 potential participants, 18 passively and 14 actively, which would have represented 21.3% of the cohort had they been included.
Chapter 4

This chapter is predominately made up of the recent manuscript submitted on the 29th of April 2018 to Musculoskeletal Science and Practice (Reference No: YMATH_2018_76). The manuscript formed part of the research project and at the end of the manuscript, there is additional information presented to contextualise the manuscript in this thesis. The additional information provides greater methodological details encompassing various aspects of the data collection process including: foot tracings, the self-balance procedure and external measures of postural alignment, inter-rater reliability and measurement reliability results.

4.1 Manucript Title

Internal and external sagittal craniovertebral alignment: A comparison between radiological and photogrammetric approaches in asymptomatic participants.

4.1.1 Secondary research questions

- Are the photogrammetric techniques used for determining stationary neutral craniovertebral postures transferable during radiographic acquisition?
- Are there differences in outcomes for stationary neutral craniovertebral posture quantification between common photogrammetric techniques and those involving direct measures through radiographic acquisition?
  - If so, how comparable are data collected using both techniques?
4.2 Abstract

**Background:** Photogrammetric measures are a commonly applied, highly reliable tool for appraising craniovertebral postures during clinical assessments, rehabilitation, and research interventions.

**Objective:** This study aimed to compare and contrast three external measures of postural alignment (EMPA) using photogrammetric and radiological approaches, and to discuss whether the CVA reflects the shape of the underlying cervical spine.

**Design:** Cross-Sectional Correlation Study.

**Method:** Young adults were included through a comprehensive written and physical screening process. Participants attended three assessment sessions (S1, S2 and S3). S1 involved a standardised photogrammetric protocol including a self-balance procedure. S2 involved radiographic image acquisition. S3 followed S1 protocol, excluding the self-balance procedure. The EMPA were recorded from all sessions and compared through paired t-tests. A multi-method radiographic classification protocol determined all cervical subtypes. The breakdown of the different cervical subtypes and their corresponding CVAs were assessed.

**Results:** There were no significant differences in all EMPA between the two photogrammetric sessions. There were significant differences in all EMPA between radiographic and photogrammetric approaches. Cervical subtype variability is present throughout the full CVA range.
Conclusions: Despite statistically significant differences between approaches, the mean differences were small and unlikely to be clinically meaningful. Accordingly, the quantification of EMPA can be undertaken with high levels of precision and reliability using photogrammetric procedures, providing standardised protocols are followed. The CVA, however, does not provide an indication of the shape of the underlying cervical spine. The inter-segmental and global variabilities, both within and between participants, negate this possibility.
4.3 Introduction

A long tradition of clinically evaluating cervical postural alignment through non-invasive photogrammetric approaches endures (do Rosario, 2014; Singla, Veqar, & Hussain, 2017), possibly due to considerations of safety, cost effectiveness, technical simplicity, and time constraints (Ashnagar et al., 2017; Cohen et al., 2017). Linear distances and angular measures are routinely evaluated on neutral craniovertebral images using standardised anatomical landmarks (Silva, Punt, Sharples, Vilas-Boas, & Johnson, 2009b; Singla et al., 2017). Whilst measures of cervical postural alignment have demonstrated moderate to excellent reliability (Ashnagar et al., 2017; Cohen et al., 2017), uncertainty remains over how well anatomical landmarks can be consistently identified through manual palpation protocols (Cohen et al., 2017; do Rosario, 2014; Robinson, Robinson, Bjorke, & Kvale, 2009).

Radiographic measurements are considered the “gold standard” when evaluating skeletal alignment (Cohen et al., 2017; D. E. Harrison et al., 2005) and are an obvious alternative for assessing postural alignment. However, ionizing radiation is a serious health concern associated with repeated radiographic measurements (Ashnagar et al., 2017; Cohen et al., 2017). This presents the clinician and researcher alike with a dilemma as to which tool to use (do Rosario, 2014). There is inconsistency in the literature regarding how well external measures of sagittal postural alignment using photogrammetric approaches relate to those measures obtained through radiography (Cohen et al., 2017; do Rosario, 2014; D. E. Harrison et al., 2005; van Niekerk, Louw, Vaughan, Grimmer-Somers, & Schreve, 2008). Irrespective of which method is used it is still unclear as to how well EMPA represents the underlying cervical curvature (Oliveira & Silva, 2016). Therefore, further work is required to clarify this issue, particularly for the purposes of establishing normative data in asymptomatic participants (Krawczky, Pacheco, & Mainenti, 2014; Singla et al., 2017).
The CVA is reported commonly throughout the literature and describes the inclination of the head with respect to the lower cervical spine (Mo, Xu, Li, & Liu, 2013). An angle less than 50° is often used to indicate the presence of FHP (Ruivo, Pezarat-Correia, & Carita, 2014). Surprisingly, despite the popularity of this measure no published research to date has reported on its relationship with underlying anatomical structures. Accordingly, the purpose of this research is to (1) compare and contrast three measures of postural alignment using photogrammetric and radiological approaches, and (2) discuss whether the CVA measure taken from radiological images reflects the shape of the underlying cervical spine.
4.4 Methods

4.4.1 Participants

The sample consisted of 150 participants aged between 18 and 30 years: 61 males (age - 22.7 ± 3.6; height - 177.5 cm ± 7.1; mass - 79.1 kg ± 14.0) and 89 females (age - 22.5 ± 3.6; height - 166.1 cm ± 6.4; mass - 63.9 kg ± 11.1). Participant eligibility was assessed with a project specific self-reporting questionnaire, SF-36, NDI and a PE as described by Daffin, Stuelcken, and Sayers (2017). All participants were asymptomatic for neck related problems at the time of testing. Approval was obtained from the institutional Research Ethics Committee (S/14/607), with written informed consent obtained from all eligible volunteers in accordance with the institutional human research ethics requirements. All aspects of this study were performed by the same researcher, a board-certified Chiropractor experienced in surface palpation and assessment of postural alignment.

4.4.2 Data collection

Participants attended 3 sessions - 2 photographic (S1 and S3) and 1 radiographic (S2) over a period of 3-4 weeks. In S1, data collection was conducted in a sequenced order in accordance with published procedures (Straker et al., 2009). A foot tracing was created for each participant in order to standardise the position of the feet during the postural assessments. Participants stood on a large sheet of paper, assuming a natural relaxed stance position while looking towards the horizon. Lines projecting from the optical axes of each camera lens were marked on the floor using adhesive tape. These lines were aligned with a cross that was marked at the centre of the BoS of the foot tracing of each participant and the paper for the tracing was fixed to the floor with blue tack.
This ensured that participants were positioned perpendicular to the optical axis of each camera and neutral craniovertebral posture was not affected by changes in foot placement (Figure 4.1) (Ferreira, Duarte, Maldonado, Bersanetti, & Marques, 2011; Gadotti & Magee, 2013; Silva, Punt, & Johnson, 2011).

*Figure 4.1. Foot tracing overlayed on a central cross representing the optical axes of both cameras, photograph by Lee Daffin.*
Five key anatomical landmarks were identified - the tip of the C7 spinous process, the left ears tragus, the left lateral canthus of the eye and the inferior margins of both ear lobes - and small (7mm) retroreflective markers adhered to rubber pads were attached using double sided tape (Silva et al., 2011). The prominent C7 spinous process was identified during cervical extension as the C6 spinous process translated anteriorly (Yip et al., 2008). Each participant was then instructed to stand barefoot on his/her foot tracing and adopt a neutral relaxed position with the arms placed at the side of the body. A self-balancing procedure was then performed to determine the true neutral head posture. Participants then closed their eyes and performed large amplitude neck flexion and extension movements that gradually decreased until a stationary balanced head position was achieved (Cuccia & Carola, 2009; Gadotti & Magee, 2013). Upon completion participants opened their eyes and verbally indicated their preparedness to remain stationary during image acquisition from both cameras. For each condition, three images were obtained in quick succession from each camera.

Two Fujifilm Finepix JX550 digital cameras were mounted onto Manfrotto 161MK2B tripods and levelled with the tripods’ inbuilt spirit level. The left sagittal plane camera was located 2.25 m from the wall (Shaheen & Basuodan, 2012) whereas the anterior frontal plane camera was located 2.5 m from the wall (Ferreira et al., 2011). Adjustable tripods permitted the optical axis of each camera to be aligned with the C7 vertebra (Ruivo et al., 2014).
S2 involved the collection of single lateral and anterior-posterior cervical radiographs, taken by the same radiographer and digital capturing unit using established radiological procedures (Daffin et al., 2017; D. E. Harrison et al., 2003). Participants were instructed to adopt a relaxed neutral erect stance position with their head looking toward the horizon. The participant’s shoulder girdles and arms hung relaxed by their sides, while their body weight was distributed evenly over both feet. The assumed position was not guided by the radiographer, and post-positioning movements were kept to a minimum (Daffin et al., 2017). Neither foot tracings nor the self-balancing procedure could be used during S2. Radiographic procedures relied on strict acquisition protocols to reduce radiation exposure. Participant’s using their foot tracings followed by the self-balancing procedure, adversely influenced the acquisition protocol. Their shoulder placement, lightly touching the wall mounted “bucky” and the tightly collimated radiation dose was negatively affected, as was the desired relaxed neutral erect stance position. S3 photogrammetric procedures were identical to those outlined in S1. The self-balancing procedure was not performed so that data from S2 and S3 could be compared.

### 4.4.3 Data reduction

The photogrammetric and radiographic images were imported and digitized on the Able Image Analyser software programme (version 3.6; http://able.mulabs.com) (Shaheen & Basuodan, 2012) and standard radiographic software (Genesis OmniVue® Genesis Digital Imaging, Inc. Los Angeles, CA) respectively. Table 4.1 describes and depicts the three measurements taken on both types of images (Silva et al., 2011; Singla et al., 2017; van Niekerk et al., 2008). The use of a vertical plumb line allowed a correction procedure to be performed that ensured that all measurements were taken relative to a ‘true’ horizontal (Ferreira et al., 2011). All measurements were recorded to the nearest 0.1 degrees (Shaheen & Basuodan, 2012).
# Measurement Descriptors, Rational and Digitization Methodologies

<table>
<thead>
<tr>
<th>Measurement Description and Rational</th>
<th>Digitization Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Cervical Gaze Angle: Sagittal Plane</strong></td>
<td>The angle is generated by marking the central points of the lateral canthus of the eye marker and the ear tragus marker (vertex). The horizontal is generated and marked by dragging the cursor to the left and adjusting the line until the program indicates a horizontal alignment has been achieved.</td>
</tr>
<tr>
<td>A line connecting the central points of the ear tragus marker and the lateral canthus of the eye marker. The UCGA is generated when a horizontal line transects the central point of the ear tragus marker. The UCGA represents the alignment of the head relative to the cervical spine (C0/C1). The UCGA varies to maintain a horizontal eye level. + values (extension) – values (flexion) (Singla et al., 2017; van Niekerk et al., 2008).</td>
<td><img src="image1.png" alt="Image" /> <img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Craniovertebral Angle: Sagittal Plane</strong></td>
<td>The angle is generated by marking the central points of the ear tragus marker and the C7 spinous process marker at the skin-marker interface (vertex). The horizontal is generated as per UCGA.</td>
</tr>
<tr>
<td>A line connecting the central point of the ear tragus marker to the tip of the C7 spinous process at the skin-marker interface. The CVA is generated when a horizontal line transects the central point of the C7 spinous processes skin-marker interface. The CVA represents variations within the head on trunk alignment. A smaller angle indicates greater forward head posture while larger angles theoretically represent an ‘ideal’ head on trunk alignment (Singla et al., 2017; van Niekerk et al., 2008).</td>
<td><img src="image3.png" alt="Image" /> <img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Lateral Head Tilt Angle: Frontal Plane</strong></td>
<td>The angle is generated by marking the central points of the inferior margins of both ear lobes at the skin-marker interface.</td>
</tr>
<tr>
<td>A line connecting the inferior margins of both ear lobes at the skin-marker interface. The LHTA is generated when a horizontal line transects the central point of the skin-marker interface of the inferior lobe. The LHTA represents coronal plane head tilt, 0° indicating perfect symmetry. + values (right lateral flexion) - values (left lateral flexion) (Silva et al., 2011; Singla et al., 2017).</td>
<td><img src="image5.png" alt="Image" /> <img src="image6.png" alt="Image" /></td>
</tr>
</tbody>
</table>

UCGA = Upper Cervical Gaze Angle, CVA = Craniovertebral Angle, LHTA = Lateral Head Tilt Angle, All Photographs and Radiographs by Lee Daffin.
The images of 50 randomly selected participants from the total cohort were assessed two weeks apart to determine the intra-rater reliability of the principal researcher when measuring each of the three postural alignment variables on both photographic and radiological images. A two-way mixed effects model (ICC\(_{3,k}\)) was used for the measures on the photographic images and a two-way mixed effects model (ICC\(_{3,1}\)) was used for the measures on the radiological images. Values for the standard error of measurement (SEM) and minimal detectable change (MDC) were also calculated and indicate low measurement error (Table 4.2).

### Table 4.2.
*Measures of Intra-Rater Reliability for the Key Photogrammetric and Radiographic Variables.*

<table>
<thead>
<tr>
<th>Angle</th>
<th>Photogrammetric Measures</th>
<th></th>
<th></th>
<th>External Radiographic Measures</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC(_{3k})</td>
<td>SEM(_{95})</td>
<td>MDC(_{95})</td>
<td>ICC(_{3,1})</td>
<td>SEM(_{95})</td>
<td>MDC(_{95})</td>
</tr>
<tr>
<td>UCGA</td>
<td>0.99</td>
<td>0.4°</td>
<td>1.0°</td>
<td>1.0</td>
<td>0.2°</td>
<td>0.5°</td>
</tr>
<tr>
<td>CVA</td>
<td>1.0</td>
<td>0.1°</td>
<td>0.4°</td>
<td>1.0</td>
<td>0.1°</td>
<td>0.3°</td>
</tr>
<tr>
<td>LHTA</td>
<td>0.99</td>
<td>0.1°</td>
<td>0.4°</td>
<td>0.99</td>
<td>0.1°</td>
<td>0.4°</td>
</tr>
</tbody>
</table>

ICC = Intraclass Correlation Coefficient, SEM = Standard Error Measurement 95% Confidence Interval, MDC = Minimal Detectable Change 95% Confidence Interval, UCGA = Upper Cervical Gaze Angle, CVA = Craniovertebral Angle, LHTA = Lateral Head Tilt Angle.

A multi-method sagittal cervical subtyping classification protocol was used to determine all 150 cervical subtypes from the radiographic images (Figure 4.2) (Daffin et al., 2017). The breakdown of the different cervical subtypes and the corresponding CVA’s were then assessed.
4.4.4 Statistical analysis

Paired t-tests were used to compare the three postural alignment measures taken on the photographic and radiological images. The alpha level was set 0.05. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) Viewer Version 22 software package (Version 22.0 for Windows, SPSS Inc., USA).

4.5 Results

There were significant differences in the CVA, UCGA and LHTA measures between radiographic and photographic images (Table 4.3). Table 4.4 is a breakdown of the different cervical subtypes based on a recently published multi-method classification protocol and the corresponding CVA angles obtained from the radiological images. The CVA data are presented in 5° increments from 30° to 70°. The percentage of lordotic or non-lordotic subtypes within each increment is also displayed.
Table 4.3.
Pairing t-Tests, Photographic Session 1 and 3 / Radiographic Session 2 and Photographic Session 3.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Photographic S1 and S3</th>
<th>Photographic S1 and S3</th>
<th>Photographic S1 and S3</th>
<th>Photographic S1 and S3</th>
<th>Photographic S1 and S3</th>
<th>Photographic S1 and S3</th>
<th>Photographic S1 and S3</th>
<th>Photographic S1 and S3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD) S1</td>
<td>M (SD) S3</td>
<td>Min S1</td>
<td>Min S3</td>
<td>Max S1</td>
<td>Max S3</td>
<td>p-value</td>
<td></td>
</tr>
<tr>
<td>UCGA</td>
<td>20.5° (5.2°)</td>
<td>20.8° (5.4°)</td>
<td>9.2°</td>
<td>6.9°</td>
<td>33.6°</td>
<td>37.4°</td>
<td>0.390</td>
<td></td>
</tr>
<tr>
<td>CVA</td>
<td>50.4° (5.2°)</td>
<td>50.2° (5.3°)</td>
<td>32.3°</td>
<td>33.4°</td>
<td>63.4°</td>
<td>66.2°</td>
<td>0.486</td>
<td></td>
</tr>
<tr>
<td>LHTA</td>
<td>0.4° (2.1°)</td>
<td>0.5° (2.0°)</td>
<td>0.0°</td>
<td>0.0°</td>
<td>7.1° (L)</td>
<td>6.8° (L)</td>
<td>0.384</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Angle</th>
<th>Radiographic S2 and Photographic S3</th>
<th>Radiographic S2 and Photographic S3</th>
<th>Radiographic S2 and Photographic S3</th>
<th>Radiographic S2 and Photographic S3</th>
<th>Radiographic S2 and Photographic S3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)S2</td>
<td>M (SD) S3</td>
<td>Min S2</td>
<td>Min S3</td>
<td>Max S2</td>
</tr>
<tr>
<td>UCGA</td>
<td>19.8° (5.1°)</td>
<td>20.8° (5.4°)</td>
<td>8.3°</td>
<td>6.9°</td>
<td>38.2°</td>
</tr>
<tr>
<td>CVA</td>
<td>51.6° (5.2°)</td>
<td>50.2° (5.3°)</td>
<td>33.1°</td>
<td>33.4°</td>
<td>64.8°</td>
</tr>
<tr>
<td>LHTA</td>
<td>0.3° (1.8°)</td>
<td>0.5° (2.0°)</td>
<td>0.0°</td>
<td>0.0°</td>
<td>4.1° (L)</td>
</tr>
</tbody>
</table>

UCGA = Upper Cervical Gaze Angle, CVA = Craniovertebral Angle, LHTA = Lateral Head Tilt Angle, L = Left Head Tilt, M = Mean, SD = Standard Deviation, Max = Maximum, Min = Minimum, S1 = Session 1, S2 = Session 2, S3 = Session 3, * = Significant Differences, p-value = <0.05.

Table 4.4.
A Breakdown of the Different Cervical Subtypes and the Corresponding Craniovertebral Angles.

<table>
<thead>
<tr>
<th>S2 CVA°</th>
<th>L</th>
<th>Non-Lordotic</th>
<th>Total</th>
<th>Total</th>
<th>Incremental %</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>St</td>
<td>GK</td>
<td>S</td>
<td>RS</td>
<td>N-L</td>
</tr>
<tr>
<td>30 to 34.9</td>
<td>1</td>
<td>1 (1)</td>
<td>100</td>
<td>0</td>
<td>2.0</td>
<td>0</td>
</tr>
<tr>
<td>35 to 39.9</td>
<td>1</td>
<td>1 (3)</td>
<td>100</td>
<td>2.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>40 to 44.4</td>
<td>9</td>
<td>3 (17)</td>
<td>52.9</td>
<td>47.1</td>
<td>19.6</td>
<td>11.1</td>
</tr>
<tr>
<td>45 to 49.9</td>
<td>15</td>
<td>1 (46)</td>
<td>32.6</td>
<td>67.4</td>
<td>49.0</td>
<td>42.4</td>
</tr>
<tr>
<td>50 to 54.9</td>
<td>17</td>
<td>1 (56)</td>
<td>30.4</td>
<td>69.6</td>
<td>82.4</td>
<td>81.8</td>
</tr>
<tr>
<td>55 to 59.9</td>
<td>8</td>
<td>1 (22)</td>
<td>36.4</td>
<td>63.6</td>
<td>98.0</td>
<td>96.0</td>
</tr>
<tr>
<td>60 to 64.9</td>
<td>1</td>
<td>1 (4)</td>
<td>25</td>
<td>75</td>
<td>100</td>
<td>98.9</td>
</tr>
<tr>
<td>65 to 70.0</td>
<td>1</td>
<td>1 (1)</td>
<td>25</td>
<td>75</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
<td>7 (99)</td>
<td>21</td>
<td>(150)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TC = Total Cohort, N-L = Non-Lordotic, L = Lordotic, St = Straight, GK = Global Kyphotic, S = Sigmoidal, RS = Reverse Sigmoidal, CVA = Craniovertebral Angle, S2 = Session 2, % = Percentage, ° = Degree.
4.6 Discussion

External measures of postural alignment are often used in both research and clinical decision making. However, doubts remain over the validity of EMPA because it is unclear whether they are representative of the shape of the underlying cervical spine. Therefore, the purpose of this study was to compare and contrast three measures of postural alignment using photogrammetric and radiological approaches, and (2) discuss whether the CVA measure taken form radiographic images reflects the shape of the underlying cervical spine using a recently developed multi-method sagittal cervical subtyping classification protocol. The results will provide important information that may help practitioners determine when to implement interventions to potentially mitigate the development of future cervical spine related problems.

The key finding of this research was that despite statistically significant differences in all EMPA when recorded using photogrammetry compared to radiologically, the mean differences ranged from only 0.2 to 1.4 degrees. Differences of such a small magnitude are unlikely to be clinically meaningful. Our results are similar to those reported in previous research where participants were either standing (G. M. Johnson, 1998) or seated (van Niekerk et al., 2008). Accordingly, the quantification of these key EMPA can be undertaken with high levels of precision and reliability using standard photogrammetric procedures.

Whilst there is now strong evidence to support the use of photogrammetry for the quantification of these key external measures of postural alignment, the second part of this project has shown that clinicians need to be cognisant that these measures do not provide an indication of the shape of the underlying cervical spine. This finding supports concerns on this issue raised by key researchers in this domain (do Rosario, 2014; Oliveira & Silva, 2016).
Our results indicate that 25 (37.3%) participants with a CVA ≤ 50° actually displayed a normal lordotic cervical alignment. Furthermore, of the 83 participants with a CVA ≥ 50°, 57 (67.5%) displayed a non-lordotic cervical alignment representing all possible subtypes. In particular, there were a large number of St-types (19) and GK-types (18) in the 50° to 59.9° range. Interestingly, the only CVA range of where there were more examples of a lordotic subtype than a non-lordotic subtype was 40° to 44.9° range. Recent evidence indicates that the number of people displaying non-lordotic subtypes is increasing in the young adult population (Daffin et al., 2017) and this may well have implications for the pathogenesis and rate of progression associated with cervical degenerative conditions (Ames et al., 2013; Nouri et al., 2015).

While attempting to understand and substantiate the inter-relationship between EMPA and the underlying alignment of the cervical spine it became evident that different cervical subtypes existed within every CVA range. The inter-segmental and global variabilities, both within and between participants, negated the possibility of relating any CVA to a particular underlying cervical shape. Our findings support previous research in this domain (G. M. Johnson, 1998). Conversely, one of the conclusions reported by van Niekerk et al. (2008) was that photographs are valid and reliable indicators of the underlying spines shape when seated. Our findings do not support this notion. The clinical determination to use radiography is standard practice when the precise nature of the underlying cervical alignment characteristics is required such as trauma, chronicity and failed outcomes when patients have not responded to administered treatment protocols. Clinicians need to be mindful of the inherent risks associated with frequent use of radiographs to assess postural alignment.
While there are some clear advantages for the use of radiography for the assessment of underlying cervical shape, some common postural conditions can be adequately quantified using photogrammetry. Clinically, postural interventions and rehabilitative procedures require collecting repeated measurements to evaluate true progression. However, clinicians need to be mindful of the limitations inherent in photogrammetry and the requirement to stringently adhere to standardised protocols during both data acquisition and analysis. A key strength of the current research lies in the strict adherence to the standardised testing protocols and we encourage clinicians to adopt this approach in both their practice and future research.

While all efforts were taken to standardise the stance position between the two procedures it likely that some variability existed. Similarly, the photogrammetric procedures were free-standing, permitting postural sway and variability within the repeated measures while the radiographic procedures relied on a single image. However, postural sway during the latter was minimised by having the participant lightly touching the bucky.
4.7 Conclusions

We believe our study is the first to provide strong evidence that key craniovertebral external photogrammetric measures of standing postural alignment demonstrate high levels of precision and reliability when compared to radiography. This research also demonstrates substantial cervical subtype variability is present throughout the full CVA range. Validating craniovertebral photogrammetric external measures have become critically important because of the increasing numbers of nonlordotic subtypes that are being observed in young populations. The latter is particularly pertinent given the links between nonlordotic subtypes and numerous degenerative conditions. At this stage conclusively validating a single sagittal external measure of postural alignment that reflects the inter-relationship of the underlying cervical vertebral alignment remains elusive.

4.8 Key Points

- Despite statistically significant differences in all EMPA when recorded using photogrammetry compared to radiologically, the mean differences were small and unlikely to be clinically meaningful.
- The quantification of these key EMPA can be undertaken with high levels of precision and reliability using photogrammetric procedures providing strict standardised protocols are followed.
- The inter-segmental and global variabilities, both within and between participants, negated the possibility of relating any CVA to a particular underlying cervical shape.
4.9 Photogrammetric Equipment

4.9.1 Cameras

Two identical Fujifilm FinePix JX550 16 megapixels cameras (Figure 4.3) weighing 113 g with external dimensions of 100 x 56 x 24 mm were used for photogrammetric acquisition. Cameras were marked allowing the same camera to be used while capturing either the coronal or the sagittal images. Both camera’s settings remained on automatic for the duration of the research project.

4.9.2 Camera mounting equipment and tripods

Two Fujifilm Finepix JX550 cameras were attached to Manfrotto 804RC2 camera mounting equipment (Figure 4.4) which in turn were mounted onto Manfrotto 161MK2B tripods equipped with inbuilt spirit level (Figure 4.5). The Manfrotto 161MK2B tripods provided a stable and adjustable support for the cameras during photogrammetric acquisition. Both the mounting equipment and the tripods are capable of being locked into a permanent position.

Figure 4.3. Fujifilm FinePix JX550 16 megapixels camera, adapted from (www.fujifilm.eu).
Figure 4.4. Manfrotto 804RC2 mounting equipment, adapted from (www.georges.com.au).

Figure 4.5. A Manfrotto 161MK2B tripod, adapted from (www.georges.com.au).
4.10 Photogrammetric Data Collection Area

A permanently established corner location within the biomechanics laboratory was used for the duration of the research project. Both tripods were positioned on measured floor marks, the tripod used to capture the left sagittal image and was located 2.25 m from the wall (G. M. Johnson, 1998; Shaheen & Basuodan, 2012), while the tripod used to capture the coronal image and was located 2.5 m from the wall (Figure 4.6) (Ferreira et al., 2011). The two Manfrotto 161MK2B tripods fitted with Manfrotto 804RC2 mounting equipment and cameras were positioned and levelled with the inbuilt spirit level. To minimise a parallax error involving an apparent difference in the position of participant when viewed from two different photographic lines of sight, Straker et al. (2009) recommend the digital camera is positioned on an adjustable tripod. Regardless of participant height, the adjustable central towers allowed the camera optical axis to be located at the level of the participant’s C7 vertebra (Ruivo et al., 2014; Silva et al., 2011).

Figure 4.6. Permanently established photogrammetric acquisition area and equipment, photograph by Lee Daffin.
4.11 Photogrammetric Equipment Calibration

Calibrating all instruments used during photogrammetric acquisition is critical to improving reliability, therefore the inbuilt spirit level on the tripods aid in camera/tripod alignment calibration. To define true vertical with each image free-hanging vertically, plumb lines were positioned slightly posteriorly of the participant for sagittal acquisition and slightly left of the participant for coronal image acquisition (Figure 4.7) (G. M. Johnson, 1998; Raine & Twomey, 1997). Plumb lines were dropped from the centre of the tripods’ adjustable central towers to either the 2.25 m or 2.5 m lines marked on the floor (Figure 4.7). The tripods’ plumb lines served two functions, firstly to set the camera-to-wall distances, and secondly the initial points at which the optical cross was generated. The points on the lines allowed each camera’s theoretical optical axis to be perpendicularly projected and outlined on the floor in front of both cameras until the lines intersected, forming an optical cross.

![Figure 4.7. Plumb lines positioning the tripods and free hanging vertical plumb lines, photograph by Lee Daffin.](image-url)
The projected perpendicular lines were permanently marked on adhesive tape adhered to the floor. The coronal and sagittal projected lines generated an optical cross at their intersection point. The optical cross provided the ability to repetitiously and accurately locate the participant’s foot tracings during the photogrammetric acquisition procedure (Figure 4.8A) (Silva et al., 2011). A single foot tracing performed during Session 1 was used throughout the research project’s photogrammetric procedures to standardise the participant’s foot position during S1 and S3. Figure 4.8B illustrates the placement of a measured foot tracing over the intersecting optical axes (Silva et al., 2011).

Figure 4.8. Permanently marked optical cross. A. Sagittal and coronal plane optical axes. B. Foot tracing overlayed on intersecting optical axes, photographs by Lee Daffin.
4.12 Participant Positioning

Silva et al. (2009a) acknowledged that a standing neutral posture is the most widely used research posture for evaluating craniovertebral postural alignment from both sagittal and coronal perspectives. Participants positioned themselves on their S1 foot tracing in the predetermined standardised location (Figure 4.8B) just anterior to the coronal planes free-hanging plumb line. To autonomously approximate the participant’s body weight evenly over both feet during the pre-photogrammetric postural positioning phase of S1, the self-balance procedure was implemented a prerequisite. All participants were shown how to perform the self-balance procedure prior to photogrammetric acquisition. The goal of the self-balance procedure is automation of a participant’s relaxed natural head, upper limb and thorax posture.

A natural head posture is attained by performing large amplitude cervical flexion and extension movements with eyes closed, then gradually decreasing this motion until a stationary comfortable balanced head position is achieved. When this is achieved, eyes are opened (Cuccia & Carola, 2009; Gadotti & Magee, 2013; D. R. Gore, 2001; Yip et al., 2008). The shoulders adopt a natural posture with both arms allowed to hang free and comfortably by the side of the thorax (Cuccia & Carola, 2009; Silva, Punt, & Johnson, 2010). The participant’s teeth are held together lightly in their habitual occlusional position to avoid the mandible influencing cervical curvature (G. M. Johnson, 1998). Verbal indications from the participant that they have achieved a balanced posture were required before image acquisition (Shaheen & Basuodan, 2012; Yip et al., 2008). Great care was taken to ensure consistency between each photogrammetric acquisition session, using standardised procedures to place the participant in the reference position to enhance angular reproducibility (G. M. Johnson, 1998).
4.13 Foot Tracing

4.13.1 Foot tracing: Background rationale

The participant-ground interface in the course of erect stance is an area of contention within the literature. Kirby, Price, and MacLeod (1987) identified that inconsistencies in the foot angle and increased stance width (inter-malleolar distances) have the potential to alter the mean position of a participant’s CoP while standing. Day, Steiger, Thompson, and Marsden (1993) determined a reduction in postural sway was observed as the participant’s stance width (inter-malleolar distances) increased. McIlroy and Maki (1997) indicated a wide range of foot positions were observed during postural testing, and suggested it is essential to standardise this variability within and between sessions, an opinion supported by Chiari, Rocchi, and Cappello (2002). McIlroy and Maki (1997) indicate a foot width distance of 17cm, and a feet opening angle of 14° was the preferred foot position.

It was determined a vital pre-requisite was the intra-individual standardisation of each participant’s foot position during session 1. A key premise of this research project was the intra-individual standardisation of cervical photogrammetric measures across all session. This premise was imperative to assist in validating the radiologically determined cervical subtypes. It has been demonstrated that stance width can affect CoP and postural sway, therefore it is not inconceivable that variability within stance width may contribute, via regional interdependence, to atypical cervical alignment patterns being adopted by the participants, thus reducing the reliability between test sessions. This project will investigate the foot angle and width in conjunction with the BoS through repeated measures across all three sessions to ascertain if transient intra-individual foot positioning variability existed. Significant detectable variability between the lordotic and non-lordotic groups, intra-
individual transient foot positioning may strengthen findings related to decreased postural control.

4.13.1.1 Foot tracing: Procedural technique

Barefooted participants stood on a sheet of paper positioned on the floor, adjacent to the photogrammetric data collection space in the biomechanics laboratory. The participants were instructed to walk onto the sheet of paper, take three big steps while standing in the same location and then assume a comfortable and relaxed standing posture with their feet positioned in a natural orientation. Once stationary, a foot tracing was performed. This tracing was used throughout the research project’s photogrammetric measures to standardise the participant’s foot position (Chiari et al., 2002; Gadotti & Magee, 2013; Kirby et al., 1987).

Chiari et al. (2002) outlined an equation for calculating a participant’s BoS based on foot placement measurements. Three measures were derived from the foot tracings: the foot width, angle of orientation (feet opening angle), and the BoS. Each foot tracing had the midpoint of the heel and the distal end of the great toe marked. The foot width is defined as the distance between the two midpoints of each heel. The foot angle is generated by joining the points at the toe and heel of each foot, then extrapolating the lines until they transect to form the feet opening angle. To estimate the BoS an equation is applied which requires three measures derived from the foot tracing. The big toe distance (BTD) and inter-malleolar distance (IMD) are linear distances between the two midpoints of the great toes and the two marked points representing the middle of each medial malleolus. The effective foot length (EFL) is the perpendicular linear distance take from the line connecting the most posterior aspects of the heals to the midpoints of the great toes (Figure 4.9).
BoS = \((BTD + IMD / 2) \times \text{mean EFL}\)

Figure 4.9. Foot anthropometry measurements. BTD = big toe distance, EFL = effective foot length, IMD = inter-malleolar distance, FW = foot width, BoS = base of support, feet opening angle, adapted from (Chiari et al., 2002), photograph by Lee Daffin.

4.13.1.2 Foot tracing: Results

All statistical analysis was performed using SPSS Viewer Version 22 software package (SPSS Inc., IBM, Chicago, Illinois). Tables 4.5 to 4.7 outline the results of the independent t-tests performed on the two groups’ foot anthropometric measures from each of the three testing sessions (lordotic \(n = 51\), nonlordotic \(n = 99\)). Levene’s test for equality of variances was applied and equal variances were assumed in each group across all three testing sessions. A Bonferroni correction was applied to determine the appropriate alpha level for each individual foot anthropometric measure, \(\alpha = 0.013\) (0.05/4).
A one-way repeated measures ANOVA was performed on the BoS for all 150 participants across S1, S2 and S3. Mauchly’s Test of Sphericity was violated ($p = 0.011$). Therefore, to determine which session was significantly different, pairwise comparisons with the alpha level set at ($p = 0.05$) were performed between S1 and S2 ($p = 0.038$), S1 and S3 ($p < 0.001$), S2 and S3 ($p = 0.017$). The pairwise comparisons determined significant differences existed between each session’s base of support.

Table 4.5
Session 1: Foot Anthropometry Measurements for the Full Cohort and Both Groups.

<table>
<thead>
<tr>
<th></th>
<th>FOA (°)</th>
<th>FW (cm)</th>
<th>BTD (cm)</th>
<th>BoS (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S1 FC M (SD)</strong></td>
<td>9.4 (10.2)</td>
<td>19.4 (4.1)</td>
<td>23.8 (6.5)</td>
<td>503.8 (149.7)</td>
</tr>
<tr>
<td>Minimum</td>
<td>-10.0</td>
<td>10.3</td>
<td>9.6</td>
<td>194.4</td>
</tr>
<tr>
<td>Maximum</td>
<td>33.0</td>
<td>32.1</td>
<td>41.5</td>
<td>995.1</td>
</tr>
<tr>
<td><strong>S1 L G1 M (SD)</strong></td>
<td>12.2 (9.1)</td>
<td>20.5 (3.9)</td>
<td>26.2 (6.1)</td>
<td>562.6 (143.7)</td>
</tr>
<tr>
<td>Minimum</td>
<td>-10.0</td>
<td>11.6</td>
<td>16.8</td>
<td>313.3</td>
</tr>
<tr>
<td>Maximum</td>
<td>30.0</td>
<td>29.2</td>
<td>41.1</td>
<td>892.4</td>
</tr>
<tr>
<td><strong>S1 N-L G2 M (SD)</strong></td>
<td>8.0 (10.5)</td>
<td>18.9 (4.2)</td>
<td>22.5 (6.4)</td>
<td>473.5 (144.2)</td>
</tr>
<tr>
<td>Minimum</td>
<td>-8.0</td>
<td>10.3</td>
<td>9.6</td>
<td>194.4</td>
</tr>
<tr>
<td>Maximum</td>
<td>33.0</td>
<td>32.1</td>
<td>41.5</td>
<td>995.1</td>
</tr>
<tr>
<td>$p$-value (0.013)</td>
<td>0.016</td>
<td>0.031</td>
<td>0.001*</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

$S1 = $ Session 1, FC = Full Cohort, L = Lordotic, N-L = Non-Lordotic, G = Group, M = Mean, SD = Standard Deviation, FOA = Feet Opening Angle, FW = Foot Width, BTD = Big Toe Distance, BoS = Base of Support, * = Significant Difference.
Table 4.6.
Session 2: Foot Anthropometry Measurements for the Full Cohort and Both Groups.

<table>
<thead>
<tr>
<th></th>
<th>FOA (°)</th>
<th>FW (cm)</th>
<th>BTD (cm)</th>
<th>BoS (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2 FC M (SD)</td>
<td>10.1 (11.5)</td>
<td>18.8 (3.8)</td>
<td>23.3 (6.4)</td>
<td>490.9 (138.7)</td>
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<tr>
<td>Minimum</td>
<td>-10.0</td>
<td>9.7</td>
<td>9.9</td>
<td>186.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>40.0</td>
<td>30.6</td>
<td>41.8</td>
<td>913.8</td>
</tr>
<tr>
<td>S2 L G1 M (SD)</td>
<td>13.4 (11.4)</td>
<td>19.1 (3.9)</td>
<td>25.3 (6.5)</td>
<td>533.2 (144.3)</td>
</tr>
<tr>
<td>Minimum</td>
<td>-8.0</td>
<td>9.7</td>
<td>12.6</td>
<td>270.2</td>
</tr>
<tr>
<td>Maximum</td>
<td>40.0</td>
<td>28.4</td>
<td>41.8</td>
<td>875.0</td>
</tr>
<tr>
<td>S2 N-L G2 M (SD)</td>
<td>8.4 (11.3)</td>
<td>18.6 (3.8)</td>
<td>22.3 (6.2)</td>
<td>469.2 (131.3)</td>
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<td>9.9</td>
<td>186.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>36.0</td>
<td>30.6</td>
<td>38.3</td>
<td>913.8</td>
</tr>
<tr>
<td>p-value (0.013)</td>
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<td>0.407</td>
<td>0.007*</td>
<td>0.007*</td>
</tr>
</tbody>
</table>

S2 = Session 2, FC = Full Cohort, L = Lordotic, N-L = Non- Lordotic, G = Group, M = Mean, SD = Standard Deviation, FOA = Feet Opening Angle, FW = Foot Width, BTD = Big Toe Distance, BoS = Base of Support, * = Significant Difference.

Table 4.7.
Session 3: Foot Anthropometry Measurements for the Full Cohort and Both Groups.

<table>
<thead>
<tr>
<th></th>
<th>FOA (°)</th>
<th>FW (cm)</th>
<th>BTD (cm)</th>
<th>BoS (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3 FC M (SD)</td>
<td>9.4 (11.1)</td>
<td>18.4 (4.0)</td>
<td>22.7 (6.2)</td>
<td>476.0 (139.1)</td>
</tr>
<tr>
<td>Minimum</td>
<td>-10.0</td>
<td>9.0</td>
<td>7.8</td>
<td>169.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>40.0</td>
<td>32.7</td>
<td>40.0</td>
<td>980.1</td>
</tr>
<tr>
<td>S3 L G1 M (SD)</td>
<td>13.4 (9.6)</td>
<td>19.0 (4.0)</td>
<td>25.2 (6.1)</td>
<td>530.4 (141.3)</td>
</tr>
<tr>
<td>Minimum</td>
<td>-4.0</td>
<td>9.5</td>
<td>12.1</td>
<td>227.7</td>
</tr>
<tr>
<td>Maximum</td>
<td>40.0</td>
<td>30.7</td>
<td>40.0</td>
<td>907.2</td>
</tr>
<tr>
<td>S3 NL G2 M (SD)</td>
<td>7.3 (11.2)</td>
<td>18.1 (3.9)</td>
<td>21.4 (5.9)</td>
<td>448.0 (129.9)</td>
</tr>
<tr>
<td>Minimum</td>
<td>-10.0</td>
<td>9.0</td>
<td>7.8</td>
<td>169.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>38.0</td>
<td>32.7</td>
<td>39.3</td>
<td>980.1</td>
</tr>
<tr>
<td>p-value (0.013)</td>
<td>0.001*</td>
<td>0.192</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

S3 = Session 3, FC = Full Cohort, L = Lordotic, N-L = Non- Lordotic, G = Group, M = Mean, SD = Standard Deviation, FOA = Feet Opening Angle, FW = Foot Width, BTD = Big Toe Distance, BoS = Base of Support, * = Significant Difference.
4.13.1.3 Foot tracing: Discussion

A foot tracing was created during S1 for each participant to standardise the position of the feet during the photogrammetric postural assessments undertaken during S1 and S3. Relative literature within the photogrammetric domain advocates for the use of standardised foot tracings during photogrammetric image acquisition. There is no evidence within the literature of any foot tracing repeated measures being performed and evaluated. It was decided that during S2 and S3 participants were to perform an identical foot tracing protocol to that performed during S1. The additional foot tracings were not used during any photogrammetric postural assessment, and were only generated to permit correlations to be performed. The aim of repeated foot tracings is to (1) determine through the BoS measure whether participants were able to reproduce similar foot positions during subsequent testing sessions, and (2) identify the strength of using a standardised foot tracing during photogrammetric image acquisition.

McIlroy and Maki (1997) indicate a foot width distance of 17 cm and feet opening angle of 14° are the average foot position. This research project identified a mean heel distance and feet opening angle across the three sessions of 19 cm and 10°. The McIlroy and Maki (1997) values were established from a mixed sample aged 19 to 97 years (n = 262, 89 male and 173 female). Allowing for the disproportionate gender balance and mismatched age demographics, the values identified in this research project are comparable. McIlroy and Maki (1997) indicated their cohort’s feet opening angle ranged from a toe-in value of -13° to a toe-out value of 52°, with the foot width distance ranging from 6 to 26 cm, whereas this research project identified values from -10° to 40° and 9 to 32.7 cm, respectively. Considering the differences previously outlined between the two cohorts, the range values are also comparable.
McIlroy and Maki (1997) suggested their recommended average foot position was completely outside the variance observed when participants were free to select their preferred stance position. The foot tracing values from this research project support the McIlroy and Maki (1997) findings that stance is individualised and varies considerably. The results of the independent t-tests performed on the two groups indicated that significant differences were observed for the feet opening angle (S2 and S3), big toe distance (S1, S2 and S3) and BoS (S1, S2 and S3) across the three testing sessions. The results suggest that lordotic participants adopt a larger feet-opening angle and BoS while standing, compared to non-lordotic participants. The relevance of this finding is unable to be determined at this time due to a lack of comparative literature to assist in the formulation of a logical statement. Pairwise comparisons determined significant differences existed between each session’s base of support. This result indicates participants are unable to reproduce similar foot positions during subsequent testing sessions.

**4.13.1.4 Foot tracing: Conclusion**

In conclusion, the participants within this research project stood with similar mean values and comparable levels of variability as previous identified. However, lordotic participants adopt a larger BoS and feet-opening angle while standing. Regardless of the group, participants are unable to reproduce similar foot positions during subsequent testing sessions. The strength of these findings supports intra-individual standardisation of a participant’s foot stance when repeated measures are required. The large between-participant variance refutes the application of an average foot position. Forcing participants to adopt an average foot position has the potential to be counterproductive, possibly guiding participants into an unnatural stance position. It is clear foot stance reproducibility in not achievable. Therefore, repositioning participants on their primary unique intra-individual foot tracing
generated while assuming a natural stance position is compelling given the current evidence and warranted when repeated measures are required.

4.14 External Measures of Postural Alignment

4.14.1 Landmark identification

Generating EMPA requires external landmarks to be palpated and precisely identified. Once the external landmarks are identified, markers must be positioned to permit angular construction. Robinson et al. (2009) identified poor inter-therapist reliability and low validity following pre and post-palpation evaluation. Unfortunately, inherent inaccuracies exist while identifying external landmarks through manual palpation protocols (do Rosario, 2014), and test-retest variances between 6 to 7.3 mm have been recorded while positioning markers (Cohen et al., 2017). These research findings prompted close attention to be focused on the palpatory identification of the relevant landmarks and the final placement of markers.

The complexity associated with palpation and identification varies considerably between landmarks. When considering the landmarks used during this research project, identifying the tip of C7 spinous process would be considered the most technically difficult landmark to identify. It is for this reason that the literature has detailed the identification process precisely. To locate the mid sagittal point related to the spinous process of C7, the researcher palpated and identified the most prominent distal cervical spinous process. The participant’s head was passively flexed and extended, resulting in the spinous process of C6 translating anteriorly and becoming absent during neck extension. The spinous process of C7 is stable during extension and represents the prominent fixed process, and once identified, it was marked. It should be noted that the C7 spinous process may take several attempts to be precisely identified (G. M. Johnson, 1998; Shaheen & Basuodan, 2012; Yip et al., 2008).
Markers were adhered mid sagittally on the tip of C7 spinous process, and posteriorly on the central midline of the left tragus and the left lateral canthus for sagittal angular generation (G. M. Johnson, 1998). Coronal angular generation required markers to be placed on the inferior margins of both ear lobes (Figure 4.10). Table 4.5 outlines the three EMPA used to assess craniovertebral alignment during this research project, consisting of the UCGA, CVA and LHTA. The identification and placement of markers during this research project was performed with a high level of precision (Table 4.2).

![Markers adhered to external landmarks of postural alignment. A. Sagittal image: 1 = left lateral canthus, 2 = left tragus, 3 = C7 spinous process. B. Coronal image: 4 and 5 = right and left inferior margins of ear lobes, photographs by Lee Daffin.]

**Figure 4.10.** Markers adhered to external landmarks of postural alignment. A. Sagittal image: 1 = left lateral canthus, 2 = left tragus, 3 = C7 spinous process. B. Coronal image: 4 and 5 = right and left inferior margins of ear lobes, photographs by Lee Daffin.

### 4.15 Photogrammetric Measurement Software

The Able Image Analyser (version 3.6; http://able.mulabs.com) photographic measurement software was used to generate all photographic angles (Shaheen and Basuodan, 2012).
During digitisation, the sequential order the angular measures were performed in remained consistent and proceeded with the CVA and UCGA on the sagittal image followed by the LHTA on the coronal image. Reliability is achieved during digitization through repetitively identifying the exact same point on the marker. Markers will either appear circular or oval on the image. A circular appearance occurs on the left lateral canthus and tragus marker, whereas an oval appearance occurs on the C7 spinous process and ear lobe markers. To accurately identify the point to mark during digitization, the image was scaled up to enlarge the required markers prior to selecting the digitization point. The point selected on the circular marker was as close as physically possible to the exact central point of the marker, taking into consideration human error and the accuracy of the digitisation software (Figure 4.11A). The point selected on the oval marker was the midline of the marker at the skin-marker interface, the same limitations concerning placement accuracy applied (Figure 4.11B). During digitization, the identified points were used to generate the angular external measures (Figure 4.12 and Figure 4.13A and B).

*Figure 4.11. Marker appearance. A. Circular marker with the central blue dot indicating the approximate centrally marked point of the marker. B. Oval marker (C7) with the blue dot indicating the marked point at the approximate midline of the marker at skin-marker interface, photographs by Lee Daffin.*
Figure 4.12. Sagittal image standardised point location on both circular and oval markers, photograph by Lee Daffin.

Figure 4.13. Digitization procedure using standardised point location on markers. A. Upper cervical gaze angle. B. Lateral head tilt angle, photographs by Lee Daffin.
4.17 Photogrammetric Image Calibration

Defining true vertical within each image was achieved through the addition of precisely located, free-hanging, vertical plumb lines. During sagittal image acquisition, the vertical plumb line was located slightly posteriorly of the participant, while it was located slightly to the left of the participant for coronal image acquisition. The vertical plumb line was visible in all imaged and used to calibrate both sagittal and coronal images. The vertical plumb lines were bricklayers no. 8 nylon strand string line, and appeared red in the images. During digitization, the proximal point of the plumb line was scaled up and the centre of the line was marked. The digitized line was dragged distally, and the centre of the line was marked. From the distally marked point, a line was dragged to the left for sagittal digitization (Figure 4.14), or either left or right depending on the side of head tilt for coronal digitization (Figure 4.15). The horizontal hatched line was adjusted either inferiorly or superiorly on the image until it appeared bright white over the hatched line indicating the line was now horizontal within the image. This digitization procedure generated an angular measure close to 90°.

Figure 4.14. Digitization of the sagittal vertical plumb line. A. < 90°. B. = 90°. C. > 90°, photographs by Lee Daffin.
Following digitization, the reported angular values generated by both the sagittal and coronal images were calibrated to the angular value identified by the digitization of their respective vertical plumb lines. If the plumb line value was less than $90^\circ$, the value that brought the plumb line value up to $90^\circ$ was added to the external measure’s values. If the plumb line value was $90^\circ$, the external measures remained unchanged. If the plumb line value was greater than $90^\circ$, the value that reduced the plumb line value down to $90^\circ$ was removed from the external measure’s values. This step in the photogrammetric procedure was the final effort to achieve a calibrated, reliable and standardised image of the participant’s true craniovertebral external measures. Table 4.8 outlines the pre and post calibrated value derived from the images in Figure 4.14 and Figure 4.15.

Figure 4.15. Digitization of the coronal vertical plumb line. **A.** $>90^\circ$ left head tilt (negative value). **B.** $<90^\circ$ right head tilt (positive value), photographs by Lee Daffin.
Table 4.8.  
**Calibrating the Plumb Line Value with the External Measures.**

<table>
<thead>
<tr>
<th>Sagittal</th>
<th>Plumb Line</th>
<th>+/ - Calibration</th>
<th>Pre-Calibration</th>
<th>Post-Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCGA</td>
<td>89.4°</td>
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<td>23.1°</td>
<td>23.7°</td>
</tr>
<tr>
<td>CVA</td>
<td>89.4°</td>
<td>+ 0.6°</td>
<td>54.1°</td>
<td>54.7°</td>
</tr>
<tr>
<td>UCGA</td>
<td>90.0°</td>
<td>0.0°</td>
<td>21.9°</td>
<td>21.9°</td>
</tr>
<tr>
<td>CVA</td>
<td>90.0°</td>
<td>0.0°</td>
<td>50.1°</td>
<td>50.1°</td>
</tr>
<tr>
<td>UCGA</td>
<td>90.3°</td>
<td>- 0.3°</td>
<td>25.9°</td>
<td>25.6°</td>
</tr>
<tr>
<td>CVA</td>
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<td>53.6°</td>
<td>53.3°</td>
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</tbody>
</table>

<table>
<thead>
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<th>Pre-Calibration</th>
<th>Post-Calibration</th>
</tr>
</thead>
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<td>- 2.6° left tilt</td>
</tr>
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<td>LHTA</td>
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<td>0.9°</td>
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</tr>
</tbody>
</table>

UCGA = Upper Cervical Gaze Angle, CVA = Craniovertebral Angle, LHTA = Lateral Head Tilt Angle.

4.18  **Photogrammetric Intra- and Inter-Rater Reliability**

As indicated in Table 4.2, intra-rater reliability for the external measures, both photogrammetric and radiographic, were shown to be excellent (ICC 0.999 to 1.0), while all standard error measurements and MDC values were < 0.5°. The images of 50 randomly selected participants from the total cohort were assessed two weeks apart to determine the inter-rater reliability of the principal researcher and a similarly skilled chiropractor. A two-way mixed effects model (ICC2,k) was used for the measures on the photographic images, and a two-way mixed effects model (ICC2,1) was used for the measures on the radiological images. Values for the SEM (≤ 0.4°) and MDC (≤ 1.2°) were also calculated and indicate low measurement error (Table 4.9).
4.19 Photogrammetric Measurement Reliability

The measurement reliability of the photogrammetric protocol was determined through a two-way mixed effects model (ICC$_{3,k}$) using the mean measures for all external measures from S1 and S3 for the entire cohort’s 150 participants. Values for the SEM (≤ 1.1°) and MDC (≤ 2.9°) were also calculated and indicate low measurement error (Table 4.9).

Table 4.9. Measures of Inter-Rater Reliability for the Key Photogrammetric and Radiographic Variables, and Photogrammetric Measurement Reliability.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Photogrammetric Measures</th>
<th>External Radiographic Measures</th>
<th>Measurement Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC$_{(2,k)}$</td>
<td>SEM$_{95}$</td>
<td>MDC$_{95}$</td>
</tr>
<tr>
<td>UCGA</td>
<td>0.99</td>
<td>0.4°</td>
<td>1.2°</td>
</tr>
<tr>
<td>CVA</td>
<td>0.99</td>
<td>0.2°</td>
<td>0.5°</td>
</tr>
<tr>
<td>LHTA</td>
<td>0.99</td>
<td>0.2°</td>
<td>0.6°</td>
</tr>
</tbody>
</table>

ICC = Intraclass Correlation Coefficient, SEM = Standard Error Measurement 95% Confidence Interval, MDC = Minimal Detectable Change 95% Confidence Interval, UCGA = Upper Cervical Gaze Angle, CVA = Craniovertebral Angle, LHTA = Lateral Head Tilt Angle.
4.20 Reported Photogrammetric External Measures of Reliability

The three external measures used photogrammetrically during this research project have been extensively investigated within the literature. Table 4.10 outlines the intraclass correlation coefficient (ICC) results from several of the key articles within this domain. The CVA has been reported as an extremely reliable anatomical head angle (Silva et al., 2009a), with the ICC ranging from 0.66 to 0.99. The UCGA is a reliable measure with the ICC ranging from 0.82 to 0.99; however, its ICC values are not reported within the literature to the same extent as the CVA. The LHTA is a reliable measure with the ICC ranging from 0.71 to 0.98; however, this measure has the least reported ICC values of the three external measures.

Table 4.10. Reported Intra-Rater Reliability for the Key Photogrammetric External Measures.

<table>
<thead>
<tr>
<th>Author(s) (Year)</th>
<th>CVA</th>
<th>UCGA</th>
<th>LHTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raine and Twomey (1997)</td>
<td>0.88</td>
<td>0.82</td>
<td>0.71</td>
</tr>
<tr>
<td>G. M. Johnson (1998)</td>
<td>0.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chansirinukor, Wilson, Grimmer, and Dansie (2001)</td>
<td>0.73 to 1.0*</td>
<td>0.73 to 1.0*</td>
<td>0.73 to 1.0*</td>
</tr>
<tr>
<td>Yip et al. (2008)</td>
<td>0.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>van Niekerk et al. (2008)</td>
<td>0.86 to 0.96</td>
<td>0.82 to 0.96</td>
<td></td>
</tr>
<tr>
<td>Silva et al. (2009a)</td>
<td>0.98 to 0.99*</td>
<td>0.98 to 0.99*</td>
<td>0.98 to 0.99*</td>
</tr>
<tr>
<td>Silva et al. (2011)</td>
<td>0.99</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>Ruivo et al. (2014)</td>
<td>0.66</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>Hazar, Karabacak, and Tiftikci (2015)</td>
<td>0.98</td>
<td>0.99</td>
<td></td>
</tr>
</tbody>
</table>

UCGA = Upper Cervical Gaze Angle, CVA = Craniovertebral Angle, LHTA = Lateral Head Tilt Angle, * = Intraclass Correlation Coefficient not specified to a given measure.
4.21 Chapter Four: Answering the Secondary Research Questions

- Are the photogrammetric techniques used for determining stationary neutral craniovertebral postures transferable during radiographic acquisition?

The two image acquisition procedures are distinct; transferability of the techniques used to acquire images through both procedures are fundamentally not transferrable. One aspect routinely used during photogrammetric image acquisition is the use of external measures of postural alignment. Landmarks are identified, then marked with marker, and they are used during the digitization process to generate standardised external measures. The ability to transfer the placement of the markers associated with these EMPA to participants prior to radiographic image acquisition is achievable. This is evident in the intra and inter-rater reliability measures associated with these external radiographic measures which exhibit excellent reliability. Both the intra- and inter-rater values for the SEM (≤ 0.2°) and MDC (≤ 0.5°) were also shown to demonstrate exceedingly small values (Table 4.2 and 4.9).

The two techniques typically involved a standing position when assessing craniovertebral alignment. While assessing the standing position both procedures acquire sagittal and coronal images. Participant positioning during photogrammetric image acquisition characteristically does not involve post-positional alterations. Strict adherence to standardised radiographic protocols requires central ray-to-participant alignment and collimation, which has the potential to generate small post-positional alterations. Each protocol has participant positioning techniques that are mandated for that protocol to successfully achieve reliable image acquisition.
Both protocols allow markedly different capacities to generate postural sway during image acquisition. The photogrammetric protocol permits participants to adopt a free-standing position which produces postural sway and variability within the repeated measures. The radiographic protocol endeavours to minimise image distortion as one image per view is all that is commonly desired due to radiation exposure. Participants are instructed to allow their shoulder to lightly touch the bucky to eliminating postural sway and minimise distortion. This radiographic procedural characteristic is in direct contrast to the free-standing position adopted during the photogrammetric protocol. In this instance the photogrammetric protocol is not transferable.

In conclusion, it is evident that during both photogrammetric and radiographic image acquisition each protocol has standardised techniques developed to suit the specific requirements of each protocol. It is clear that photogrammetric techniques used for determining stationary neutral craniovertebral postures are not transferable. However, it is apparent that one procedure commonly used during photogrammetric image acquisition is transferable. The placement of markers on external landmarks used to generate external measures is achievable during radiographic image acquisition. It appears that marker placement is the only photogrammetric procedure that is transferable without contributing detrimentally to the established standardised radiographic protocol.

- Are there differences in outcomes for stationary neutral craniovertebral posture quantification between common photogrammetric techniques and those involving direct measures through radiographic acquisition?
  - If so, how comparable are data collected using both techniques?
There were significant differences in all three external measures between radiographic and photogrammetric measures generated during S2 and S3. (Table 4.3). However, the mean differences ranged from only 0.2 to 1.4°, with the CVA exhibiting 1.4°, the UCGA 1.0° and the LHTA 0.4°. Differences of such a small magnitude (Figure 4.16) are unlikely to be clinically meaningful when contrasted with the photogrammetric measures MDC findings identified in Table 4.2 and 4.9. Our results are similar to those reported in previous research in which participants were either standing (G. M. Johnson, 1998) or seated (van Niekerk et al., 2008). G. M. Johnson (1998) reported mean differences ranging from 1.1° to 2.7° between non-identical radiographic measures and the CVA measure determined photogrammetrically. van Niekerk et al. (2008) indicated strong correlations between identical radiographic and photographic measures. This study demonstrated mean differences between the two approaches of 1.1° for the CVA and 1.6° for the UCGA.

Figure 4.16. Protractor indicating zero, one and two degrees, image by Lee Daffin.
Procedural characteristics when reporting the final external measures may contribute to the mean differences observed when comparing images from S2 and S3. Photogrammetric external measures are initially calibrated to a digitized angular measure generated by incorporating the vertical plumb line located within the image. The final, reported calibrated external measures were determined through a procedure described textually in section 4.17 (Photogrammetric Image Calibration) while, the different numerical steps involved in the calibration process are demonstrated in Table 4.8. Calibration regardless of the precision taken represents the first point where small errors can potentially occur. The final, reported calibrated external measures were generated from the mean of three calibrated images (Table 4.3). The photogrammetric external measures are also generated in the presence of postural sway which can slightly vary the identified external measures between consecutive images.

This is in contrast the reported radiographic external measures which are not calibrated post acquisition as the bucky is pre-calibrated and levelled against the wall. Therefore, radiographs are not subject to the small errors that can potentially occur during the photogrammetric calibration procedure. Radiographic external measures are reported as single uncalibrated values (Table 4.3) and are, therefore, not calibrated mean values typically generated during the photogrammetric procedure. The participant’s capacity to produce postural sway is considerably reduced during radiographic image acquisition due to the participant lightly touching their shoulder against the bucky.

Accordingly, continued research could involve establishing an acceptable degree of measurement difference between radiographic external measures when compared with photogrammetric external measures. Also, both radiographic and photogrammetric external measures can be contrasted, between asymptomatic and symptomatic participants, to establish an acceptable degree of measurement difference between different protocols and the
symptomatic status of the participants. Research of this nature may improve validity and reliability concerning FHP assessment during photogrammetric procedures.

In conclusion, although significant differences were observed in all three external measures between radiographic and photogrammetric, this finding must be put into context. As discussed, while answering the first of this chapter’s secondary research questions, each protocol has standardised techniques developed to suit the specific requirements of each protocol, and thus are uniquely different. Quantification of external measures through both radiographic and photogrammetric protocols is achieved through distinctly different procedures. Small mean differences may appear as statistically significant differences suggesting that the two protocols are not comparable. However, assessing the magnitude of the differences between the mean measures it is apparent the MDC values are of a similar magnitude.

The MDCs determined while assessing photogrammetric measurement reliability, intra- and inter-rater reliability were determined to be $\leq 2.9^\circ$ for both sagittal measures and $\leq 0.9^\circ$ for the coronal measure. The mean difference for all three measures between S2 and S3 was $\leq 1.4^\circ$ for both sagittal measures and $\leq 0.4^\circ$ for the coronal measure (Figure 4.16). The MDCs evaluated from the photogrammetric external measures are approximately twice that of the mean difference for all three measures when considered from a sagittal and coronal perspective. Therefore, the mean values are all smaller than the minimal amount of change required to distinguish a true change in an external measure from a change due to measurement error. It is clear from the available evidence that EMPA determined through radiographic and photogrammetric image acquisition are clinically comparable when strict adherence to standardised protocols are followed.
Chapter 5

The textual structure of this chapter will predominantly constitute material taken, in its entirety, from the first published article associated with this research project. The Journal of Craniovertebral Junction & Spine accepted this material for publication in August 2017, without any amendments required. Additional radiographic measures were investigated and not introduced within this chapter’s published material. These measures were outside the scope required to precisely classify cervical subtypes, and are introduced following this chapter’s published material. The succeeding sub-section designated to radiographic measures and additional detailed material is required to satisfactorily answer this chapter’s second research question.

5.1 Manuscript Title


5.1.1 Secondary research questions

- During radiographic subtype classification are the different methodologies consistently classifying each subtype, or are potential inter-methodological inconsistencies affecting subtype classification?
- Do the commonly cited radiographic measures of sagittal cervical alignment act as potential indicators of postural control?
5.2 Abstract

**Aims:** The aim of this study is to (1) compare and contrast cervical subtype classification methods within an asymptomatic population, and (2) identify inter-methodological consistencies and describe examples of inconsistencies that have the potential to affect subtype classification and clinical decision-making.

**Methods:** A total of 150 asymptomatic 18–30-year-old participants met the strict inclusion criteria. An erect neutral lateral radiograph was obtained using standard procedures. The Centroid, modified Takeshima/Herbst methods and the relative rotation angles in cases of nonagreement were used to determine subtype classifications. Cohen’s kappa coefficient (κ) was used to assess the level of agreement between the two methods.

**Results:** Non-lordotic classifications represented 66% of the cohort. Subtype classification identified the cohort as, lordosis (51), straight (37), global kyphosis (28), sigmoidal (13), and reverse sigmoidal (21). Cohen’s kappa coefficient indicated that there was only a moderate level of agreement between methods (κ = 0.531). Methodological agreement tended to be higher within the lordotic and global kyphotic subtypes whereas, straight, sigmoidal, and RS subtypes demonstrated less agreement.

**Conclusion:** This is the first study of its type to compare and contrast cervical classification methods. Subtypes displaying predominantly extended or flexed segments demonstrated higher levels of agreement. Our findings highlight the need for establishing a standardised multi-method approach to classify sagittal cervical subtypes.
5.3 Introduction

The cervical spine is naturally lordotic (Abelin-Genevois, Idjerouidene, Roussouly, Vital, & Garin, 2014; Nouri et al., 2015), contributing to the spine’s overall sagittal balance in association with the interconnected alignment variabilities within the thoracolumbar spine, pelvis, and lower limbs (Ames et al., 2013; Wainner et al., 2007). A distinction must be made between methods that are used to classify cervical alignment subtypes and methods that produce angular measurements. The Centroid (Ohara et al., 2006; Ruangchainikom et al., 2014), Kamata’s line drawing (Chiba et al., 2006; Okada et al., 2009), Takeshima (Takeshima et al., 2002) and Herbst (Herbst, 1980) methods are commonly used to classify cervical subtypes. The Cobb, Posterior Tangent (RRA) (D. E. Harrison, Harrison, Cailliet, et al., 2000; Janusz, Tyrakowski, Yu, & Siemionow, 2016; Ohara et al., 2006; Scheer et al., 2013; Silber, Lipetz, Hayes, & Lonner, 2004), Cervical Centroid Lordosis and Ishihara methods (Ohara et al., 2006) all produce angular measurements that quantify the curve, but not its specific subtype.

Descriptive assessment of the various cervical alignment subtypes has improved considerably. Ruangchainikom et al. (2014) introduced the term global kyphosis to describe both a global flexed segmental arrangement and also the concept of focal kyphotic sections within the lower or upper cervical spine of sigmoidal-types. D. D. Harrison et al. (1996) described various subtypes within the cervical spine. These subtypes are typically classified as lordotic (L-type), straight (St-type), global kyphotic (GK-type), sigmoidal (S-type), and reverse sigmoidal (RS-type). Cervical subtype classification involves identifying and using numerous radiological landmarks to develop an overall impression of the cervical spine’s sagittal alignment. A variety of visual and numerical methods have been developed and
modified over time to fulfil this requirement (Herbst, 1980; Ohara et al., 2006; Takeshima et al., 2002).

The Centroid method (Ohara et al., 2006; Ruangchainikom et al., 2014) involves visually determining the location and numerical distance of centrally located points within the vertebral bodies of C3–C6 to a central line connecting C2 and C7. The Takeshima method (Takeshima et al., 2002) involves visually identifying the inherent sequential alignment of the posterior vertebral body margins (PVBM) from C2 to C7. The generated PVBM conformational shape (CSh) is classified according to its relative subtype. Conversely, the Herbst method (Herbst, 1980) requires visual interpretation of the convergence or divergence posteriorly of five lines that equally transect the intervertebral discs between C2 and C7. At present, no single “gold standard” methodology exists to classify sagittal cervical alignment subtypes. However, these are the most accepted methods within the literature.

Considerable advances have been made regarding the various non-lordotic subtypes and their contribution to the pathogenesis of degenerative cervical myelopathy (DCM), and the significant impact that this has on the quality of life of the elderly (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015; Patwardhan et al., 2015; Smith et al., 2013). Two recent reports have independently determined that approximately one-third of asymptomatic participants displayed non-lordotic subtypes (Faline et al., 2007; Le Huec et al., 2015). The mounting evidence that non-lordotic subtypes are increasing within apparently healthy populations is concerning considering the detrimental effects of DCM (Ames et al., 2013; Diebo, Varghese, Lafage, Schwab, & Lafage, 2015; Nouri et al., 2015; Tetreault et al., 2015). As DCM is the leading cause of spinal cord dysfunction worldwide (Smith et al., 2013) an increase in non-lordotic subtypes could indicate a potential future rise in DCM symptomatology in the general population.
Cervical subtyping is essential within research and clinical environments (Chiba et al., 2006; Ohara et al., 2006; Okada et al., 2009; Scheer et al., 2013) to establish baseline and postintervention alignment classifications. Pre- and post-operative decision making relies on an accurate understanding of the various cervical alignment subtypes, as sagittal alignment influences operative outcomes (Chiba et al., 2006; Park et al., 2013; Scheer et al., 2013; Suda et al., 2003). Scheer et al. (2013) suggested the necessity for a comprehensive approach to assess global cervical-pelvic relationships. Therefore, a precise understanding of the limitations within cervical subtyping methodologies is critical to achieve this future direction.

Accordingly, the purpose of this research is to (1) compare and contrast cervical subtype classification methods within an asymptomatic population, and (2) identify inter-methodological agreement and describe areas of disagreement that have the potential to affect subtype classification and clinical decision-making. It is hoped that this will stimulate further research and discussion that leads to the development of a standardised sagittal subtyping classification method.
5.4 Methods

The sample population consisted of 61 male and 89 female participants (Table 5.1). The tools that were used to assess participant eligibility were a PSQ (Cuccia & Carola, 2009; Kogler et al., 2000; Raine & Twomey, 1997; Silva & Cruz, 2013; Yu et al., 2011), SF-36 (Ware Jr & Sherbourne, 1992), NDI (Vernon & Mior, 1991), and a PE (Cipriano, 2010; Magee, 2014). The PSQ was formulated from published criteria to exclude participants that could negatively influence asymptomatic measures. All included participants demonstrated an asymptomatic PSQ, with all health and neuromusculoskeletal SF-36 scores above the National Health Survey SF-36 population norms (Australian Bureau of Statistics, 1995). In addition, the NDI upper limit inclusion score was 12, where a score >15 was likely to indicate neck pathology (Kato et al., 2012). The PE excluded participants that demonstrated positive neurological and/or orthopaedic findings.

Table 5.1.
*Cohort Demographic Measures Shown as Means ± 1 SD.*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cohort (n = 150)</th>
<th>Male (n = 61)</th>
<th>Female (n = 89)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>22.5 (3.6)</td>
<td>22.7 (3.6)</td>
<td>22.5 (3.6)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71 (0.09)</td>
<td>1.78 (0.07)</td>
<td>1.66 (0.06)</td>
</tr>
<tr>
<td>Range (m)</td>
<td>1.49 - 1.96</td>
<td>1.62 - 1.96</td>
<td>1.49 - 1.89</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>70.1 (14.4)</td>
<td>79.1 (14.0)</td>
<td>63.9 (11.1)</td>
</tr>
<tr>
<td>Range (kg)</td>
<td>45.0 - 128.0</td>
<td>53.3 - 128.0</td>
<td>45.0 - 95.5</td>
</tr>
</tbody>
</table>

*n = Number of Participants.
Approval was obtained from the Institutional Research Ethics Committee (S/14/607), with written informed consent obtained from all eligible volunteers in accordance with the institutional human research ethics requirements. The current study is one component of a larger project investigating the influence of cervical alignment on postural sway. This accounts for the radiographic procedures on asymptomatic subjects.

5.4.1 Radiographic procedures, instruments, and measurements

A single lateral radiograph was taken with a tube-to-wall mounted Bucky distance of 1.5 m. The central ray was aligned approximately at the level of C4. Each participant was positioned with their right shoulder touching the Bucky and instructed to adopt a relaxed neutral erect stance position with their head looking toward the horizon. The participant’s shoulder girdles and arms hung relaxed by their sides, while their body weight was distributed evenly over both feet (Vedantam et al., 2000). The assumed position was not guided by the radiographer, and post positioning movements were kept to a minimum (Gadotti & Magee, 2013; D. R. Gore, 2001; D. E. Harrison et al., 2003; G. M. Johnson, 1998; Silva et al., 2011). All radiographs were taken by the same radiographer and digital capturing unit. The principal researcher classified all modified Takeshima/Herbst Method curvatures on standard radiographic software (Genesis OmniVue © Genesis Digital Imaging, Inc., Los Angeles, CA, USA), with all images digitized at a scale of 1.0 then printed for Centroid classification.
5.4.2 Modified Takeshima/herbst method

The Takeshima and Herbst methods have been combined, as both individual visual methods complement each other’s subtype classification criteria. A continuous posterior vertebral body line (PVBL) was drawn connecting the posterior inferior corner of the C2 vertebral body to the posterior superior corner of the C7 vertebral body (Takeshima et al., 2002). Intervertebral disc lines (IVDL) were established within the IVD spaces from C2/3 to C6/7 by drawing lines that equally transected the along its anterior to posterior axis. The five transecting lines were interpreted depending on their visual convergence or divergence posteriorly to the PVBL (Herbst, 1980). The PVBL CSh and IVDL alignments were compared to the subtype classification guidelines to finalize classification. In the modified Takeshima/Herbst method subtype classification guidelines. L-type: The PVBL CSh is lordotic, all the IVDL converge posteriorly. St-type: The PVBL CSh indicates linearity, all the IVDL are parallel. GK-type: The PVBL CSh is kyphotic, all the IVDL diverge posteriorly. S-type: The upper sub-axial spines (C2/C4) PVBL CSh is lordotic while the lower sub-axial spine (C5/C7) is kyphotic. The upper sub-axial IVDL converge. RS-type: The upper sub-axial spines (C2/C4) PVBL CSh is kyphotic while the lower sub-axial spine (C5/C7) is lordotic. The upper sub-axial IVDL converge posteriorly while the lower sub-axial IVDL converge posteriorly (Figure 5.1).

Figure 5.1. Modified Takeshima / Herbst method sub-type classification guidelines, adapted from (Herbst, 1980; Takeshima et al., 2002), illustration by Lee Daffin.
5.4.3 Centroid method

The Centroid method utilizes a combination of numerical and visualization techniques to classify alignment. Centroids represent the intersection point of two lines within the vertebral bodies of C3–C6. The first line connected the anterior inferior corner of the vertebral body to the posterior superior corner of the vertebral body while the second line connected the anterior superior corner of the vertebral body to the posterior inferior corner of the vertebral body. The C2–C7 Centroid determination line (CDL) was generated by connecting two points. The first point was located centrally on the inferior endplate of C2 while the second point was located centrally on the superior endplate of C7 (Ohara et al., 2006; Ruangchainikom et al., 2014). Measured relationships of the Centroids to the CDL are outlined within the subtype classification guidelines. In the Centroid method, subtype classification guidelines. L-type: All Centroids are located anteriorly to the CDL; at least, one Centroid is ≥2 mm from the CDL. St-type: The Centroids can be located anterior or posteriorly to the CDL however, all Centroids must lay ≤2 mm from the CDL. GK-type: All Centroids are located posteriorly to the CDL; at least, one Centroid is ≥2 mm from the CDL. S-type: One upper cervical Centroid must be located anteriorly to the CDL while one lower cervical Centroid must be located posteriorly to the CDL. One Centroid regardless of location must be ≥2 mm from the CDL. RS-type: One upper cervical Centroid must be located posteriorly to the CDL while one lower cervical Centroid must be located anteriorly to the CDL. One Centroid regardless of location must be ≥2 mm from the CDL (Figure 5.2).
5.4.4 Relative rotation angle

When methodological inconsistency occurred, five individual RRA were generated from C2/3 to C6/7. These intersegmental angles are measured at the intersection of consecutive PVBLs (Figure 5.3) (D. D. Harrison et al., 1996; Janusz et al., 2016; Ohara et al., 2006).

Figure 5.2. Centroid Method sub-type classification guidelines, adapted from (Ohara et al., 2006; Ruangchainikom et al., 2014), illustration by Lee Daffin.

Figure 5.3. C4/5 Relative rotation angle guidelines. A. Segmental flexion (positive angular value) is indicated when the inferior PVBL projects posteriorly after intersecting the superior PVBL. B. Segments measuring ≤ 2º were considered parallel. C. Segmental extension (negative angular value) is indicated when the inferior PVBL projects anteriorly after intersecting the superior PVBL. radiographs by Lee Daffin.
5.4.5 Final classification subtyping

Subtyping was performed separately on different copies of the same radiographs to limit the influence of previously determined classifications derived from the alternative method. Classification difficulties occurred when methods tended not to agree. Selecting a specific subtype to represent the participant involved simultaneously reviewing both marked radiographs in conjunction with the RRA measures, then comparing the collective findings with their relative guidelines. Final subtype classification was only achievable once the RRA flexion and extension findings were matched with the guidelines.

5.4.6 Statistical evaluation of methodological agreement

Cohen’s kappa coefficient (κ) was used to assess the level of agreement between the two methods, taking into account the agreement occurring by chance. The magnitude of the kappa coefficient was evaluated according to the criteria established by Landis and Koch (1977). (<0 no agreement, 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–1 almost perfect agreement).
5.5 Results

Subtype numbers and percentages for each sex and the cohort as a whole are outlined within Table 5.2. The largest percentage (34.0%) of the cohort was classified in the L-type.

5.5.1 Statistical evaluation of methodological agreement

Methodological consistency occurred on 94 (62.7%) occasions while methods tended not to agree 56 (37.3%) times. When agreement by chance was taken into account only a moderate level of agreement was identified, $\kappa = 0.531$ (53.1%). Statistical analyses were completed using SPSS Viewer Version 22 software package (SPSS Inc., IBM, Chicago, Illinois).

Table 5.2.
The Number of Female (n=89, 59.3%) and Male (n=61, 40.7%) Participants Within Each of the Sub-Type Classifications. Data Presented as n (% of cohort).

<table>
<thead>
<tr>
<th>Sub-type</th>
<th>Female</th>
<th>Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female Cohort</td>
<td>% of Total Cohort</td>
<td>Male Cohort</td>
</tr>
<tr>
<td>L-type</td>
<td>$n = 22$ (24.8%)</td>
<td>14.7%</td>
<td>$n = 29$ (47.5%)</td>
</tr>
<tr>
<td>St-type</td>
<td>$n = 23$ (25.8%)</td>
<td>15.3%</td>
<td>$n = 14$ (22.9%)</td>
</tr>
<tr>
<td>GK-type</td>
<td>$n = 26$ (29.2%)</td>
<td>17.3%</td>
<td>$n = 2$ (3.3%)</td>
</tr>
<tr>
<td>S-type</td>
<td>$n = 9$ (10.1%)</td>
<td>6.1%</td>
<td>$n = 4$ (6.6%)</td>
</tr>
<tr>
<td>RS-type</td>
<td>$n = 9$ (10.1%)</td>
<td>6.1%</td>
<td>$n = 12$ (19.7%)</td>
</tr>
</tbody>
</table>

Data presented as n (% of cohort), L-type = Lordotic, St-type = Straight, GK-type = Global Kyphotic, S-type = Sigmoidal, RS-type = Reverse Sigmoidal, $n =$ Number of Participants.
The method used to select each participant’s subtype is outlined in Table 5.3. Methodological consistency was greater within the L and GK-type curves. Conversely, in approximately 60% of cases, St, S, and RS-types were selected by a single method alone (Figure 5.4, 5.5 and 5.6). In cases where a subtype was classified by only a single method, Tables 5.4 and 5.5 show how the classification of each subtype differs between the two methods. Figure 5.4, 5.5 and 5.6 provide specific examples of single method subtype classifications.

Table 5.3. Quantification of Cervical Sub-Type Classifications According to Each Method.

<table>
<thead>
<tr>
<th>Sub-type</th>
<th>Selected by both Methods</th>
<th>Selected only by Centroid Method</th>
<th>Selected only by Modified Takeshima/Herbst Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-type</td>
<td>n = 46 (90.2%)</td>
<td>n = 4</td>
<td>n = 1</td>
</tr>
<tr>
<td>St-type</td>
<td>n = 13 (35.1%)</td>
<td>n = 24</td>
<td>n = 0</td>
</tr>
<tr>
<td>GK-type</td>
<td>n = 24 (85.7%)</td>
<td>n = 4</td>
<td>n = 0</td>
</tr>
<tr>
<td>S-type</td>
<td>n = 4 (30.8%)</td>
<td>n = 0</td>
<td>n = 9</td>
</tr>
<tr>
<td>RS-type</td>
<td>n = 7 (33.3 %)</td>
<td>n = 1</td>
<td>n = 13</td>
</tr>
</tbody>
</table>

Data presented as n (% of cohort), L-type = Lordotic, St-type = Straight, GK-type = Global Kyphotic, S-type = Sigmoidal, RS-type = Reverse Sigmoidal, n = Number of Participants.

Figure 5.4. GK-type selected by the Centroid Method and how the Modified Takeshima/Herbst Method selected and classified the same curvature as a RS-type, radiographs by Lee Daffin.
Figure 5.5. S-type selected by the Modified Takeshima/Herbst Method and how the Centroid Method selected and classified the same curvature as a St-type, radiographs by Lee Daffin.

Figure 5.6. RS-type selected by the Modified Takeshima/Herbst Method and how the Centroid Method selected and classified the same curvature as a St-type, radiographs by Lee Daffin.
5.6 Discussion

Cervical spine subtype classification methods must be reliable, interchangeable, and reduce bias (Janusz et al., 2016; Ohara et al., 2006). Several investigators have performed comparative (Janusz et al., 2016; Ohara et al., 2006; Silber et al., 2004) and reliability (D. E. Harrison, Harrison, Cailliet, et al., 2000) studies on commonly performed cervical angular measures. However, this is the first study, to our knowledge, that has compared and contrasted established cervical subtype classification methods within an asymptomatic population. When comparing cervical subtype classification methods, it was surprising to observe only a moderate level of agreement (53.1%). Our findings indicate that both methods display bias, the Centroid method selects St-types over S and RS-types whereas the modified Takeshima/Herbst method selects S and RS-types over St-types (Tables 5.4 and 5.5). Therefore, depending upon the classification method used to assess a single presentation, different cervical subtypes may be selected. This has implications for clinical decision-making.

The three factors responsible for most of the inconsistencies in subtype classification were, (1) segmental flexion (their number, location, and degree), (2) the large segmental extension angles located at the upper (C2/3) and lower (C6/7) sub-axial spine, and (3) the S and RS-type transitional region (either C3/4, C4/5 or C5/6) between the upper and lower sub-axial cervical curves. In cases where inconsistencies arose, further investigation of the radiographs RRA flexion and extension findings and subtyping guidelines was undertaken. A classification decision was reached when the collective methodological and RRA evidence supporting the selection of one method’s subtype could not be refuted by the alternative.
Consistency between classification methods appears to be enhanced when there is a greater number of extended (L-type 90.2%) or flexed (GK-type 85.7%) segments in sequence. Importantly, complete segmental extension is only observed within the L-type classification, a fact that appeared to account for the greater consistency between the two methods when classifying this subtype. Conversely, none of the GK-type classifications displayed complete segmental flexion throughout the entire cervical spine. Our data indicate that the upper (C2/3) and lower (C6/7) segments within the GK-type typically display extension. The combination of extended and flexed cervical segments in a region of the vertebral column that should display predominately extension may contribute to the moderate level of classification inconsistencies observed between the two methods. Specific differences in the classification guidelines for the non-lordotic subtypes resulted in classification inconsistencies in approximately two-thirds of the participants demonstrating St, S, and RS-types.

The Centroid method (Figure 5.2) uses numerical distances and visual placement of the Centroids to a CDL whereas the modified Takeshima/Herbst method (Figure 5.1) uses visual recognition of the PVBL’s CSh and the posterior convergence or divergence of the IVDLs. PVBM is a highly reliable spinal landmark however, the vertebral endplates exhibit inter-participant angular variability (D. E. Harrison, Harrison, Cailliet, et al., 2000). The Cobb method reliably uses vertebral endplates to assess and regularly report cervical angular measures (Ames et al., 2013). Our findings are consistent with those from Ohara et al. (2006) who concluded correlations were strong within all angular measures related to the L-type and weaker among the non-lordotic classifications.
The Centroid method’s classification guideline for the GK-type allowed the identification of all the Centroids posteriorly to the CDL with one Centroid ≥2 mm from the CDL indicating all GK-type cases. Conversely, the modified Takeshima/Herbst method appeared to be influenced by the segmental extension located at the upper (C2/3) or lower (C6/7) segments. Accordingly, the PVBL and posteriorly converged C2/3 on C3/4 or C5/6 on C6/7 IVDL were identified as either an S or RS-type (Figure 5.4). This no doubt contributed to the modified Takeshima/Herbst methods over selecting these two subtypes and under selecting the GK-type. However, in pronounced S or RS-type curves, the consistency between each method increases markedly. The Centroid method has a propensity to over select the number of St-type classifications within shallow S and RS-type curvatures, leading to an under selection within these two classifications (Table 5.4). The Centroids within these shallow sigmoidal types fell either anterior or posterior to the CDL but at no location were the Centroids ≥2 mm from the CDL.

Table 5.4. Sub-Types Selected by the Centroid Method and How the Alternative Method Selected and Classified the Same Curvature.

<table>
<thead>
<tr>
<th>Selected only by the Centroid Method</th>
<th>How the Modified Takeshima/Herbst Method select the same curve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L-type</td>
</tr>
<tr>
<td>L-type</td>
<td>n = 4</td>
</tr>
<tr>
<td>St-type</td>
<td>n = 24</td>
</tr>
<tr>
<td>GK-type</td>
<td>n = 4</td>
</tr>
<tr>
<td>S-type</td>
<td>n = 0</td>
</tr>
<tr>
<td>RS-type</td>
<td>n = 1</td>
</tr>
</tbody>
</table>

L-type = Lordotic, St-type = Straight, GK-type = Global Kyphotic, S-type = Sigmoidal, RS-type = Reverse Sigmoidal, n = Number of Participants.
While classifying the St-type one problem was that all cases with Centroid locations ≤2 mm from the CDL were selected into this subtype. In contrast, the extremely rigid St-type guidelines for the modified Takeshima/Herbst method allows only a linear PVBL CSh and parallel IVDL to be selected, potentially contributing to a smaller number of this subtype selected by this method (Table 5.4 and 5.5). Conversely, within shallow curvatures, these small visual discrepancies in the PVBL and the nonparallel IVDL appear to allow over selection of S and RS-type classifications by the modified Takeshima/Herbst method (Table 5.4). Anteriorly located Centroids (at least one Centroid ≥2 mm from the CDL) permitted an L-type classification (Figure 5.2). However, when inconsistencies arose, the modified Takeshima/Herbst method classified these curves as S or RS-types (Table 5.4). In contrast, an opposite scenario was observed when using the modified Takeshima/Herbst method (Table 5.5) whereby the PVBL CSh and the nonparallel IVDL allowed the selection of S or RS-types rather than the Centroid method’s St-type classification (Figure 5.5 and Figure 5.6). Our research highlights that shallow sigmoidal curves with small focal kyphotic regions are difficult to classify consistently with either method.

Table 5.5.
Sub-Types Selected by the Modified Takeshima/Herbst Method and How the Alternative Method Selected and Classified the Same Curvature.

<table>
<thead>
<tr>
<th>Selected only by the Modified Takeshima/Herbst Method</th>
<th>How the Centroid Method select the same curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-type</td>
<td>n = 1</td>
</tr>
<tr>
<td>St-type</td>
<td>n = 0</td>
</tr>
<tr>
<td>GK-type</td>
<td>n = 0</td>
</tr>
<tr>
<td>S-type</td>
<td>n = 9</td>
</tr>
<tr>
<td>RS-type</td>
<td>n = 13</td>
</tr>
</tbody>
</table>

L-type = Lordotic, St-type = Straight, GK-type = Global Kyphotic, S-type = Sigmoidal, RS-type = Reverse Sigmoidal, n = Number of Participants.
A potential limitation of the current study was that only one researcher was responsible for classifying all subtypes through both methods and the final subtype selection. To mitigate any potential errors, all images were assessed on three occasions to formulate the final selected subtype. This comparative methodological investigation has revealed the likelihood for considerable differences in the classification of certain cervical subtypes depending on which one of the two methods is applied. The Centroid method is well suited to determine L, St, and GK-types, whereas, the modified Takeshima/Herbst method is suited to determine L, GK, S, and RS-types. The Centroid methods use of the Centroid to CDL measurement adds a level of numerical analysis not present within the modified Takeshima/Herbst method, however the visualization of the PVBL and IVDL utilized by the modified Takeshima/Herbst method offers an alternative alignment perspective not offered by the Centroid method.

5.7 Conclusion

Our research reinforces the need for multimethod contrasting in conjunction with the RRA measure to accurately assess and report non-lordotic subtypes. Clinical decision-making and prognostic determination require establishing precise baseline cervical subtype classifications to permit reliable pre- and post-image contrasting during postintervention appraisal. With an increasing trend toward non-lordotic alignment (Faline et al., 2007; Le Huec et al., 2015), evidence-based care will encourage the reporting of therapeutic interventions and outcomes with ever increasing alignment accuracy. To increase reliability, validity, and cross correlation of clinical and research findings, our study highlights the need for establishing a standardised multi-method approach to classify sagittal cervical subtypes.
5.8 **Key Points**

- Non-lordotic subtypes were demonstrated by 99 out of the 150 (66.0%) participants.
- Methodological consistency occurred on 94 (62.7%) occasions while inconsistency was identified 56 (37.3%) times. When agreement by chance was taken into account, only a moderate level of agreement was identified, $\kappa = 0.531$ (53.1%).
- Consistency was higher while classifying the L and GK-types. Conversely, classification of non-lordotic patterns varies depending on the method selected.
- The challenges presented to clinicians to correctly classifying cervical sagittal alignment may be reduced when a multi-method approach is undertaken, thus strengthening classification validity.
- A classification decision in cases of inconsistency can be reached when methodological and RRA measures are considered together.
- Our research provided a detailed descriptive appraisal that could be used to standardise cervical alignment classification for reporting purposes.
5.9 Radiographic Sub-Section

As conferred, additional radiographic measures were investigated and not included within the published material as they reside outside the scope necessary to classify cervical subtypes. Radiographic measures produce angular measurements that quantify the curve, but not its specific subtype. This chapter’s subsequent sections serve two primary functions: (1) provide detailed augmentation of methodological protocols where required to generate the reliable radiographs used during this research project, and (2) provide the introduction to the background rationales, methodological protocols, results, discussions and conclusions associated with the additional radiological measures investigated and required to answer this chapter’s second research question.
5.10 Radiographic Participation Preparation

To allow an exact radiographic representational overlay of the assessed photogrammetric measures investigated in this research project, steel markers were adhered to the five key anatomical landmarks (Figure 5.7) identified previously in Session 1 (Silva et al., 2011). The landmarks included:

A. The tip of the C7 spinous process.

B. The left ear’s tragus.

C. The left lateral canthus of the eye.

D. The inferior margins of both ear lobes.

*Figure 5.7. Key photogrammetric anatomical landmarks, radiographically overlayed. A. Tip of the C7 spinous process. B. Left ears tragus. C. Left lateral canthus of the eye. D. Inferior margins of both ear lobes, radiograph by Lee Daffin.*
5.11 Radiographic De-Identified

Legal requirements dictate that a participant’s name is required on all radiographs taken, whether for clinical or research purposes. During the processing protocol, all radiographs were de-identified. As each radiograph was copied, the participant’s name was not copied, and the image file was coded (A/P001 to 150 and/or LATERAL001 to 150) and saved into the participant’s unique coded research folder (Postural Sway: PS001 to PS150). This de-identification protocol allowed interclass correlations to be performed without any knowledge of the participant that provided the radiograph (Gadotti & Magee, 2013; Marchiori et al., 1997).

5.12 Standardisation of Radiographic Measures and Analysis Software

All radiographic measures were generated on the “Genesis Digital Imaging” software platform (Genesis OmniVue ®, Inc., Los Angeles, CA, USA) except for the radiographic measures associated with the Centroid method. It was determined that the technical difficulties related to accurately generating Centroid method measures with this software were problematic. The capacity of the software to generate each centroid, the CDL, and then accurately measure the distances (≤4mm) from each centroid to the CDL, was not exactly what the software was designed to perform. It was determined that accurate Centroid method measures needed to be generated manually on printed lateral radiographs. The primary concern with this process was the accurate scaling of the printed radiographs.
This concern was overcome through the measurement of the steel markers used to generate the photogrammetric measures on the radiographs. Several steel markers were measured with a vernier caliper (Figure 5.8) and a mean measure of 7mm was established. The steel markers were measured on several scaled printed radiographs ranging from 0.8 to 1.2. The most accurate steel marker measure representing 7mm was identified on printed radiographs scaled at a factor of 1.0 (Figure 5.7). Following this finding, all lateral cervical radiographs from LATERAL001 to 150 were printed at a scale of 1.0, bound together in a document and used to determine all Centroid method classification for this research project. This research project implemented the suggestion by Yip et al. (2008) to improve measurement standardisation, and if the measurement mark fell between two whole numbers on the measurement device, the smaller number was recorded.

*Figure 5.8. Vernier caliper measurement of the steel photogrammetric landmark marker, photograph by Lee Daffin.*
5.13 Radiological Measurement Software

Linear and angular measures were generated on the “Genesis Digital Imaging” software (Genesis OmniVue ®, Inc., Los Angeles, CA, USA) and transferred to Microsoft Excel initially on Microsoft Office Version 2013, then Version 2016 (Microsoft Corp., Redmond, WA, USA) when it was released.

5.14 Lateral Radiographic Measures

5.14.1 Posterior tangent method

Radiographic measurements of the cervical spine can be appreciated from both a segmental and global perspective. The posterior tangent method is a versatile measurement protocol that uses the PVBM, a very stable anatomical feature, as a basis by which the measures are generated. In the cervical spine between C2 and C7 the standardised nomenclature used to express the generated global absolute rotation angle is ARA_{C2-C7}. Segmentally, a similar protocol can be applied to the cervical spine’s individual segments. The PVBM of adjacent vertebrae are used to generate the RRA, and the standardised nomenclature used to express these global angles are RRA_{C2-C3}, RRA_{C3-C4}, RRA_{C4-C5}, RRA_{C5-C6} and RRA_{C6-C7}. By convention, if the ARA or RRA is in extension (lordotic), the angular value is expressed as a negative value whereas, in flexion (kyphotic), the angular value is expressed as a positive value (D. D. Harrison et al., 2004; D. D. Harrison et al., 1996; D. E. Harrison, Harrison, Cailliet, et al., 2000).
5.14.1.1 Absolute rotation angle C2-C7

The ARA_{C2,C7} is defined and generated by parallel tangents (lines) projected along the PVBMs, one generated line is projected distally from C2, the other generated line is projected proximally from C7 (Figure 5.9). At the point the two tangents intersect, the angular measure is subtended. Cervical extension (negative) is recognised when the C2 tangent is orientated anterior to the C7 tangent whereas, flexion (positive) is recognised when the C2 tangent is orientated posteriorly to the C7 tangent (D. D. Harrison et al., 1996; D. E. Harrison, Harrison, Cailliet, et al., 2000; Janusz et al., 2016; Kuntz IV et al., 2007). No significant difference between repeated ARA_{C2,C7} measures taken 8 months apart was identified (D. E. Harrison et al., 2003).

*Figure 5.9.* Absolute rotation angle C2-C7. **A.** Lordotic (extension: negative value): C2 tangent is orientated anterior to the C7 tangent. **B.** Kyphotic (flexion: positive value): C2 tangent is orientated posteriorly to the C7 tangent, radiographs by Lee Daffin.
5.14.1.2 Relative rotation angle (RRAC2-C3 to C6-C7)

The five individual RRA\textsubscript{C2-C3} to RRA\textsubscript{C6-C7} measures are defined and generated by parallel tangents (lines) projected along the PVBMs, one generated line is projected distally from the superior vertebra and the other generated line is projected proximally from the inferior vertebra. At the point the two tangents intersect, the angular measure is subtended. The measures are identified as extension or flexion in an identical manner to the ARA\textsubscript{C2-C7} (Figure 5.3). The sum of the intersegmental angles from RRA\textsubscript{C2-C3} to RRA\textsubscript{C6-C7} can subsequently generate an alternative ARA\textsubscript{C2-C7} measure (D. D. Harrison et al., 1996; D. E. Harrison, Harrison, Cailliet, et al., 2000; Janusz et al., 2016; Ohara et al., 2006). No significant difference between repeated RRA\textsubscript{C2-C3} to RRA\textsubscript{C6-C7} measures taken 3 and 8 months apart was identified (D. E. Harrison et al., 2003).

5.14.2 Anterior translation of the head measure

The ATHM is defined as a proximally projecting vertical line from the posterior inferior corner of the C7 vertebral body. A perpendicular line is projected from the posterior superior corner of the C2 vertebral body to transect the proximally projecting vertical line (Figure 5.10). The linear distance of the perpendicular line implies the sagittal vertical axis of the head’s CoM relative to C7 vertebra (Figure 5.10). The distance is measured in millimetres with a positive value indicated when the posterior superior corner of the C2 vertebral body is located anterior to perpendicular line, whereas a negative value is indicated when the identified point on C2 is located posterior to perpendicular line (D. D. Harrison et al., 1996). No significant difference between repeated ATHMs taken 3 and 8 months apart was identified (D. E. Harrison et al., 2003).
Figure 5.10. The anterior translation of the head measure (ATHM). A. Lordotic subtype exhibiting an ATHM of 16.8mm. B. Global kyphotic subtype exhibiting an ATHM of 16.2mm, radiographs by Lee Daffin.

5.14.3 Atlas angle (C1 angle)

The atlas angle, as described, is referred to by various titles. The atlas plane line (APL) transects the mid points of the anterior and posterior tubercles of the atlas. A horizontal line is subtended to the APL to generate the atlas angle (Figure 5.11) (positive values, ALP tilts anterior superior, negative values, ALP tilts anterior inferior) (D. D. Harrison et al., 1996; Ling, Chevillotte, Thompson, Bouthors, & Le Huec, 2018; Takasaki et al., 2011).
5.14.4 C0-C2 angle (Occiput-C2 angle)

The C0-C2 angle as described is referred to by various titles. The McGregor line is represented by a line projecting posteriorly from the posterosuperior margin of the hard palate to the inferior most margin of the occipital bone. The angle subtended by McGregor’s line and a line traversing the IVD space of C2-C3, parallel to the inferior endplate of C2, indicates the C0-C2 angle (Figure 5.11) (positive values, C2 line tilts anterior inferior, negative values, C2 line tilts anterior superior) (Abelin-Genevois et al., 2014; Kuntz IV et al., 2008; Le Huec et al., 2015; Ling et al., 2018; Park et al., 2013).

Figure 5.11. C0-C2 angle and atlas angle. A. Lordotic subtype. B. Global Kyphotic subtype, radiographs by Lee Daffin.
5.14.5 C2 slope

The C2 slope is an angle subtended by a line generated parallel to the inferior endplate of C2 transecting a horizontal line (Figure 5.12) (positive values, C2 line tilts anterior inferior, negative values, C2 line tilts anterior superior) (Ling et al., 2018; Smith et al., 2013).

5.14.6 C7 slope

The C7 slope in an angle subtended by a line generated parallel to the inferior endplate of C7 transecting a horizontal line (Figure 5.12) (positive values, C7 line tilts anterior inferior, negative values, C7 line tilts anterior superior) (Ling et al., 2018; Smith et al., 2013).

![Figure 5.12. C2 and C7 slope. A. Lordotic subtype. B. Global Kyphotic subtype, radiographs by Lee Daffin.](image-url)
5.14.7 Lateral radiographic measures: Results

All statistical analysis was performed on SPSS Viewer Version 22 software package (SPSS Inc., IBM, Chicago, Illinois). Tables 5.6 and 5.7 outline the results of the independent t-tests performed on the two groups’ 12-sagittal cervical radiographic measures (lordotic \( n = 51 \), non-lordotic \( n = 99 \)). Equal variances were not assumed for \( \text{RRA}_{C6-C7} \) and total RRA. A Bonferroni correction was applied to determine the appropriate alpha level for each individual radiographic measure, \( \alpha = 0.004 \ (0.05/12) \).

The following scale was used to interpret the size of the correlation coefficient: 0.00 to 0.30 Negligible; 0.30 to 0.50 Low Positive; 0.50 to 0.70 Moderate Positive; 0.70 to 0.90 High Positive; 0.90 to 1.00 Very High Positive (Mukaka, 2012). A Pearson correlation was performed to determine the relationship between the \( \text{ARA}_{C2-C7} \) and Total RRA for all 150 participants, \( r = 0.938 \). A Very High Positive correlation was demonstrated between the \( \text{ARA}_{C2-C7} \) and Total RRA measures.

The radiological images of 50 randomly selected participants from the total cohort were assessed two weeks apart to determine the intra- and inter-rater reliability of the principal researcher and a similarly skilled chiropractor. A two-way mixed effects model (ICC3,1) was used for the intra-rater reliability measures, while a two-way mixed effects model (ICC2,1) was used for the inter-rater reliability measures. Standard error measurement and MDC were assessed through the identified two-way random effects model with a 95% confidence interval. The following scale was used to interpret ICC values: \(< 0.40 = \text{Poor Agreement} \), \( 0.40 < 0.75 = \text{Good Agreement} \), and \( > 0.75 = \text{Excellent Agreement} \) (Janusz et al., 2016). All intra-rater (ICC3,1) (0.76 to 0.99) and inter-rater (ICC2,1) (0.79 to 0.96) measures exhibited Excellent Agreement (Table 5.8).
Table 5.6.
Radiographic Measures for the Absolute Rotation Angle C2-C7, Anterior Translation of the Head Measure, Atlas Angle, C0-C2 Angle, C2 Slope and C7 Slope, for the Full Cohort and the Two Groups.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>p-value (&lt;0.004)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC ARA_{C2-C7} (°)</td>
<td>-13.9 (10.0)</td>
<td>12.2</td>
<td>-35.4</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>-23.3 (6.2)</td>
<td>-11.1</td>
<td>-35.4</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>-9.1 (7.9)</td>
<td>12.2</td>
<td>-34.2</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>FC ATHM (mm)</td>
<td>23.6 (11.0)</td>
<td>-14.0</td>
<td>61.7</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>23.8 (11.6)</td>
<td>2.6</td>
<td>61.7</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>23.5 (10.7)</td>
<td>-14.0</td>
<td>54.1</td>
<td>0.866</td>
</tr>
<tr>
<td>FC Atlas Angle (°)</td>
<td>12.8 (6.5)</td>
<td>-6.7</td>
<td>31.2</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>15.2 (6.5)</td>
<td>1.7</td>
<td>31.2</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>11.6 (6.2)</td>
<td>-6.7</td>
<td>24.2</td>
<td>0.001*</td>
</tr>
<tr>
<td>FC C0-C2 Angle (°)</td>
<td>16.4 (7.2)</td>
<td>-3.4</td>
<td>36.0</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>13.1 (7.6)</td>
<td>-3.4</td>
<td>31.5</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>18.1 (6.3)</td>
<td>3.3</td>
<td>36.0</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>FC C2 Slope (°)</td>
<td>17.9 (7.4)</td>
<td>-2.3</td>
<td>36.3</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>13.8 (7.2)</td>
<td>-2.3</td>
<td>31.4</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>20.1 (6.5)</td>
<td>2.4</td>
<td>36.3</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>FC C7 Slope (°)</td>
<td>22.6 (7.8)</td>
<td>3.9</td>
<td>42.8</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>28.2 (6.6)</td>
<td>14.2</td>
<td>42.8</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>19.8 (6.8)</td>
<td>3.9</td>
<td>35.1</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

FC = Full Cohort, ARA_{C2-C7} = Absolute Rotation Angle C2-C7, ATHM = Anterior Translation of the Head Measure, C0-C2 = Occiput - Second Cervical Vertebra, C2 = Second Cervical Vertebra, C7 = Seventh Cervical Vertebra, SD = Standard Deviation * = Significant Difference, positive = Flexion, negative = Extension.
Table 5.7. 
Radiographic Measures for the Relative Rotation Angle C2-C3 to C6-C7 and the Total Relative Rotation Angle, for the Full Cohort and the Two Groups.

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>p-value (&lt;0.004)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC RRA&lt;sub&gt;C2-C3&lt;/sub&gt; (°)</td>
<td>-4.7 (4.7)</td>
<td>-17.6</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>-4.9 (4.3)</td>
<td>-17.5</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>-4.6 (5.0)</td>
<td>-17.6</td>
<td>8.2</td>
<td>0.790</td>
</tr>
<tr>
<td>FC RRA&lt;sub&gt;C3-C4&lt;/sub&gt; (°)</td>
<td>-1.8 (4.6)</td>
<td>-16.2</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>-4.6 (3.8)</td>
<td>-16.2</td>
<td>3.5</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>-0.4 (4.3)</td>
<td>-15.0</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>FC RRA&lt;sub&gt;C4-C5&lt;/sub&gt; (°)</td>
<td>-1.0 (5.1)</td>
<td>-18.8</td>
<td>14.6</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>-4.8 (4.2)</td>
<td>-18.8</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>0.9 (4.4)</td>
<td>-9.4</td>
<td>14.6</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>FC RRA&lt;sub&gt;C5-C6&lt;/sub&gt; (°)</td>
<td>-0.7 (4.8)</td>
<td>-13.5</td>
<td>13.9</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>-3.8 (3.9)</td>
<td>-13.5</td>
<td>2.6</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>0.8 (4.4)</td>
<td>-9.8</td>
<td>13.9</td>
<td></td>
</tr>
<tr>
<td>FC RRA&lt;sub&gt;C6-C7&lt;/sub&gt; (°)</td>
<td>-5.8 (4.8)</td>
<td>-19.2</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>-6.9 (3.5)</td>
<td>-16.8</td>
<td>-0.3</td>
<td></td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>-5.2 (5.3)</td>
<td>-19.2</td>
<td>10.7</td>
<td>0.025</td>
</tr>
<tr>
<td>FC Total RRA (°)</td>
<td>-14.0 (11.1)</td>
<td>-44.3</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>-24.8 (6.2)</td>
<td>-44.3</td>
<td>-14.4</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>-8.5 (8.6)</td>
<td>-36.3</td>
<td>12.5</td>
<td></td>
</tr>
</tbody>
</table>

FC = Full Cohort, RRA = Relative Rotation Angle, SD = Standard Deviation, * = Significant Difference, positive = Flexion, negative = Extension, C2 = Second Cervical Vertebra, C7 = Seventh Cervical Vertebra.
Table 5.8. 
*Measures of Intra and Inter-Rater Reliability for the 12 Sagittal Cervical Radiographic Measures.*

<table>
<thead>
<tr>
<th></th>
<th>Intra-Rater</th>
<th></th>
<th>Inter-Rater</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC(3,1)</td>
<td>SEM$_{95}$</td>
<td>MDC$_{95}$</td>
<td>ICC(2,1)</td>
</tr>
<tr>
<td>ARA$_{C2-C7}$</td>
<td>0.96</td>
<td>2.3°</td>
<td>6.4°</td>
<td>0.90</td>
</tr>
<tr>
<td>ATHM</td>
<td>0.99</td>
<td>0.8 mm</td>
<td>2.2 mm</td>
<td>0.96</td>
</tr>
<tr>
<td>Atlas Angle</td>
<td>0.98</td>
<td>0.8°</td>
<td>2.3°</td>
<td>0.95</td>
</tr>
<tr>
<td>C0-C2 Angle</td>
<td>0.99</td>
<td>0.1°</td>
<td>0.4°</td>
<td>0.87</td>
</tr>
<tr>
<td>C2 Slope</td>
<td>0.92</td>
<td>2.0°</td>
<td>5.5°</td>
<td>0.86</td>
</tr>
<tr>
<td>C7 Slope</td>
<td>0.97</td>
<td>1.3°</td>
<td>3.7°</td>
<td>0.90</td>
</tr>
<tr>
<td>RRA$_{C2-C3}$</td>
<td>0.87</td>
<td>1.7°</td>
<td>4.7°</td>
<td>0.81</td>
</tr>
<tr>
<td>RRA$_{C3-C4}$</td>
<td>0.85</td>
<td>1.9°</td>
<td>5.3°</td>
<td>0.79</td>
</tr>
<tr>
<td>RRA$_{C4-C5}$</td>
<td>0.78</td>
<td>2.3°</td>
<td>6.5°</td>
<td>0.80</td>
</tr>
<tr>
<td>RRA$_{C5-C6}$</td>
<td>0.76</td>
<td>2.2°</td>
<td>6.2°</td>
<td>0.83</td>
</tr>
<tr>
<td>RRA$_{C6-C7}$</td>
<td>0.82</td>
<td>2.0°</td>
<td>5.6°</td>
<td>0.80</td>
</tr>
<tr>
<td>Total RRA</td>
<td>0.93</td>
<td>3.0°</td>
<td>8.2°</td>
<td>0.88</td>
</tr>
</tbody>
</table>

ICC = Intraclass Correlation Coefficient, SEM = Standard Error Measurement 95% Confidence Interval, MDC = Minimal Detectable Change 95% Confidence Interval, ARA$_{C2-C7}$ = Absolute Rotation Angle C2-C7, ATHM = Anterior Translation of the Head Measure, RRA = Relative Rotation Angle, C0-C2 = Occiput - Second Cervical Vertebra, C2 = Second Cervical Vertebra, C7 = Seventh Cervical Vertebra.

5.14.7.1 *Lateral radiographic measures: Discussion*

A distinction must be made between methods that are used to classify cervical alignment subtypes and methods that produce angular measurements. All of the 12 sagittal cervical radiographic measures investigated are unable to classify the cervical curve, and only serve to identify the angular or linear distance between two osseous points. The ARA$_{C2-C7}$, ATHM and Total RRA are three measures that provide a relatively global perspective of the cervical region, while the remaining measures indicated segmental angular measures or vertebral alignment relative to a horizontal plane. Measures of intra- and inter-rater reliability for the 12 sagittal cervical radiographic measures exhibit *Excellent Agreement.*
D. E. Harrison, Harrison, Cailliet, et al. (2000) and Silber et al. (2004) suggest the ARA\textsubscript{C2-C7} demonstrates greater accuracy and reliability when estimating sagittal cervical alignment parameters, compared to the Cobb method. D. E. Harrison, Harrison, Cailliet, et al. (2000) report that the ARA\textsubscript{C2-C7} can accurately depict cervical sagittal alignment within lordotic curves. This characteristic may be indicated within the lordotic curve; however, Figures 5.15A, 5.15C and 5.16 demonstrate that the ARA\textsubscript{C2-C7} cannot accurately depict cervical sagittal alignment within non-lordotic curves. The ARA\textsubscript{C2-C7} is well reported within the literature, with Kuntz IV et al. (2007) pooling estimates of the mean values and reported an ARA\textsubscript{C2-C7} of -17.0° (± 14.0°). D. D. Harrison et al. (1996) reported an ARA\textsubscript{C2-C7} of -34.0° (± 9.4°) in a population of 252 specifically selected lordotic radiographs. This research project reported a full cohort ARA\textsubscript{C2-C7} of -13.9° (± 10°), a lordotic ARA\textsubscript{C2-C7} value of -23.3° (± 6.2°) and a non-lordotic ARA\textsubscript{C2-C7} value of 9.1° (± 7.9°), with a significant difference identified between the groups.

The reported full cohort ARA\textsubscript{C2-C7} value from this research project was 3° less than the estimates reported by Kuntz IV et al. (2007). This finding is less than the ARA\textsubscript{C2-C7} MDC of 6.4°; however, the reported increase in non-lordotic subtypes within the younger population potentially contributed to this research project’s ARA\textsubscript{C2-C7} value. D. D. Harrison et al. (1996) reported a lordotic ARA\textsubscript{C2-C7} value of -34.0°, a value approximately 10° greater than this research project’s ARA\textsubscript{C2-C7} value. The D. D. Harrison et al. (1996) ARA\textsubscript{C2-C7} value could potentially differ from this research project’s value due to the large sample of D. D. Harrison et al. (1996). Alternatively, this smaller lordotic ARA\textsubscript{C2-C7} value may indicate that within the young lordotic population, the lordosis is reducing as a functional consequence of the habitual use of modern technology. The sum of the five segmental RRA\textsubscript{C2-C3} to RRA\textsubscript{C6-C7} measures establishes the Total RRA measure. A Very High Positive Pearson correlation \(r = \)
0.938) was exhibited between the ARA$_{C2-C7}$ and Total RRA, indicating that a very close relationship exists between the two measures.

The RRA$_{C2-C3}$ to RRA$_{C6-C7}$ measures represent individual, intersegmental measures at each level within the cervical spine. However, when added together, they represent the Total RRA. As identified by the Very High Positive correlation between the ARA$_{C2-C7}$ and the Total RRA, the sum of the RRA measures reflects the overall angular measure of the sagittal cervical spine. It could be argued that the Total RRA reflects the true angular measure of the sagittal cervical spine as it takes into consideration all the intersegmental angles, whereas the ARA$_{C2-C7}$ only represents the proximal and distal vertebral alignment of the sagittal cervical spine. Two measures that did not exhibit significant differences between the two groups were the RRA$_{C2-C3}$ ($p = 0.790$) and RRA$_{C6-C7}$ ($p = 0.025$). This result could be interpreted mechanistically, as these two intersegmental regions are located proximally and distally within the most flexible region of the spine.

Regardless of the cervical subtype, the mean intersegmental angles at RRA$_{C2-C3}$ and RRA$_{C6-C7}$ were $-4.7$ ($\pm 4.7$) and $-5.8$ ($\pm 4.8$), respectively. Accordingly, D. D. Harrison et al. (1996) reported values of this magnitude within their specifically selected lordotic population, indicating intersegmental extension is advantageous at these levels. The intervening RRA measures located between RRA$_{C2-C3}$ and RRA$_{C6-C7}$ all exhibited significant differences between the two groups. The mean RRA$_{C3-C4}$ to RRA$_{C5-C6}$ lordotic values recorded extension values similar to those reported at RRA$_{C2-C3}$ and RRA$_{C6-C7}$, whereas the RRA$_{C3-C4}$ to RRA$_{C5-C6}$ non-lordotic values were close to zero, indicating a near parallel intersegmental alignment. Interpreting the mean RRA$_{C3-C4}$ to RRA$_{C5-C6}$ non-lordotic values suggests that the intersegmental levels from C3/4 to C5/6 are more likely to exhibit intersegmental flexion when compared to their corresponding C2/3 and C6/7 segments.
D. D. Harrison et al. (1996) reported an ATHM value of 15.4 mm (±10.2 mm) within the specifically selected lordotic radiographs. A full cohort ATHM of 23.6 mm (±11.0 mm) was reported, which was larger than the D. D. Harrison et al. (1996) reported value. The ATHM represents only one of three measures that exhibited no significant difference between the two groups. This finding indicates that regardless of which cervical subtype a participant exhibits, the mean ATHM is greater than that exhibited within a specifically selected lordotic population two decades prior. One significant societal change that has occurred in the past two decades, that has possibly instigated this increased anteriorly translated craniovertebral posture, is the ubiquitous increase in the use of modern technology. This research project reported the full cohort’s atlas angle value as 12.8° (± 6.5°), with a significant difference exhibited between the two groups. D. D. Harrison et al. (1996) reported from their lordotic sample an atlas angle value of 24.0° (± 7.4°) which represents a value approximately twice that of this research project’s value.

This research project reported the lordotic group’s atlas angle as 15.2° (±6.5°), which is considerably lower than the value reported by D. D. Harrison et al. (1996) established from their lordotic sample. As previously discussed, the reduced atlas angle value could be a compensatory mechanism, compelled to decrease due to the habitual use of modern technology and its capacity to reduce the lordotic alignment within the younger population. Kuntz IV et al. (2007) pooled estimates of the mean values and reported the C0/2 angle as 14.0° (± 7.0°). Alternatively, Nojiri et al. (2003) reported a mean C0/2 angle of 15.3° (± 8.3°) in a mixed asymptomatic sample aged 11 to 77 (n = 313), while Le Huec et al. (2015) reported a mean C0/2 angle of 15.8° (± 7.2°) in a mixed asymptomatic sample aged 18 to 76 (n = 106). Park et al. (2013) reported a mean C0/2 angle of 15.4° (± 8.4°) in a mixed asymptomatic sample segregated into two groups aged 20 to 29 and 60 to 74 (n = 100).
et al. (2013) reported a mean C0/2 angle of 16.4° (± 7.9°) for the 50 participants aged 20 to 29.

This research project reported the full cohort’s C0/2 angle as 16.4° (± 7.2°) with a significant difference exhibited between the two groups. This research project reported value is of a similar magnitude to other reported asymptomatic C0/2 angle values, and identical to the Park et al. (2013) reported value of 16.4° recorded from their younger participants. It appears that the mean asymptomatic C0/2 angle is relatively stable between similar age groups and different age ranges. However, the mean representation of the C0/2 angle changes considerably when the non-lordotic subtype is segregated according to its specific classified subtypes (Table 5.9).

The GK-type mean C0/2 angle was shown to be 21.0° (± 4.6°) which is considerably larger than the reported mean C0/2 angle value. Iyer et al. (2016) reported cervical radiographic measures from pre-operative degenerative cervical myelopathic patients aged 29 to 84 (n = 90), indicating that the mean C0/2 angle value as 21.6° (± 9.2°). Iyer et al. (2016) correlated these measures with their NDI scores to determine if radiographic measures could be used as an independent predictor of pre-operative disability. While several measures exhibited significant differences between the two groups, the C0/2 angle value was shown to be $p = 0.051$ just falling short of exhibiting a significant difference between the two groups. It is concerning that asymptomatic GK-type C0/2 angles are almost identical to the values observed in pre-operative patients.
Table 5.9.
The C0-C2 Angle: Full Cohort, the Two Groups and Individual Non-Lordotic Subtypes.

<table>
<thead>
<tr>
<th>Subtype</th>
<th>Mean (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC C0-C2 Angle (°)</td>
<td>16.4 (7.2)</td>
<td>-3.4</td>
<td>36.0</td>
<td>39.4</td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>13.1 (7.6)</td>
<td>-3.4</td>
<td>31.5</td>
<td>34.9</td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>18.1 (6.3)</td>
<td>3.3</td>
<td>36.0</td>
<td>32.7</td>
</tr>
<tr>
<td>St-Type</td>
<td>18.4 (6.0)</td>
<td>4.8</td>
<td>29.7</td>
<td>24.9</td>
</tr>
<tr>
<td>GK-Type</td>
<td>21.0 (4.6)</td>
<td>12.6</td>
<td>31.2</td>
<td>18.6</td>
</tr>
<tr>
<td>S-Type</td>
<td>14.4 (4.6)</td>
<td>7.0</td>
<td>21.5</td>
<td>14.5</td>
</tr>
<tr>
<td>RS-Type</td>
<td>15.9 (7.9)</td>
<td>3.3</td>
<td>36.0</td>
<td>32.7</td>
</tr>
</tbody>
</table>

FC = Full Cohort, C0-C2 = Occiput - Second Cervical Vertebra, St-Type = Straight, GK-Type = Global Kyphosis, S-Type = Sigmoidal, RS-Type = Reverse Sigmoidal, SD = Standard Deviation.

This research project reported the full cohort’s C2 slope as 17.9° (± 7.4°) with a significant difference exhibited between the two groups. Smith et al. (2013) correlated radiographic measures and health-related quality of life scores within pre-operative degenerative cervical myelopathic patients with an average age of 55.4 (n = 56). Smith et al. (2013) reported the C2 slope as 22.1° (± 9.5°), a mean value very similar to the C2 slope values exhibited by the asymptomatic participants with GK-type and to a lesser extent S-type non-lordotic subtypes (Table 5.10). The C2 slope value was shown to correlate (p = 0.036) significantly with the modified Japanese Orthopaedic Association scale, a tool used to establish mild, moderate and severe impairment in degenerative cervical myelopathic patients. It is also concerning that asymptomatic GK and S-type C2 slope values are similar to the values observed in pre-operative patients, and the C2 slope has been shown to correlate significantly with degenerative cervical myelopathic impairment.
Table 5.10.
*The C2 slope: Full Cohort, the Two Groups and Individual Non-Lordotic Subtypes.*

<table>
<thead>
<tr>
<th>Subtype</th>
<th>Mean (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC C2 Slope (°)</td>
<td>17.9 (7.4)</td>
<td>-2.3</td>
<td>36.3</td>
<td>38.6</td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>13.8 (7.2)</td>
<td>-2.3</td>
<td>31.4</td>
<td>33.7</td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>20.1 (6.5)</td>
<td>2.4</td>
<td>36.3</td>
<td>33.9</td>
</tr>
<tr>
<td>St-Type</td>
<td>20.1 (5.5)</td>
<td>4.7</td>
<td>30.8</td>
<td>26.1</td>
</tr>
<tr>
<td>GK-Type</td>
<td>23.2 (4.1)</td>
<td>15.0</td>
<td>29.6</td>
<td>14.6</td>
</tr>
<tr>
<td>S-Type</td>
<td>17.4 (5.8)</td>
<td>8.9</td>
<td>29.1</td>
<td>20.2</td>
</tr>
<tr>
<td>RS-Type</td>
<td>17.2 (9.0)</td>
<td>2.4</td>
<td>36.3</td>
<td>33.9</td>
</tr>
</tbody>
</table>

FC = Full Cohort, C2 = Second Cervical Vertebra, St-Type: Straight, GK-Type: Global Kyphosis, S-Type: Sigmoidal, RS-Type: Reverse Sigmoidal, SD = Standard Deviation.

This research project reported the full cohort’s C7 slope as 22.6° (± 7.8°) with a significant difference exhibited between the two groups. The degree of the C7 slope is significantly correlated with cervical sagittal alignment. The larger the C7 slope, the greater the L-type curve, whereas a non-lordotic subtype has a greater probability of transpiring when the C7 slope is small (Le Huec et al., 2015). The C7 slope values outlined in Table 5.11 support the recognised relationship between the C7 slope and the corresponding cervical sagittal alignment, as the minimum L-type C7 slope value is similar to the mean GK-type C7 slope value.
Table 5.11.  
*The C7 Slope: Full Cohort, the Two Groups and Individual Non-Lordotic Subtypes.*

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC C7 Slope (°)</td>
<td>22.6 (7.8)</td>
<td>3.9</td>
<td>42.8</td>
<td>38.9</td>
</tr>
<tr>
<td>Lordotic Group 1</td>
<td>28.2 (6.6)</td>
<td>14.2</td>
<td>42.8</td>
<td>28.6</td>
</tr>
<tr>
<td>Non-Lordotic Group 2</td>
<td>19.8 (6.8)</td>
<td>3.9</td>
<td>35.1</td>
<td>31.2</td>
</tr>
<tr>
<td>St-Type</td>
<td>21.4 (5.7)</td>
<td>7.9</td>
<td>34.4</td>
<td>26.5</td>
</tr>
<tr>
<td>GK-Type</td>
<td>15.5 (5.7)</td>
<td>3.9</td>
<td>26.6</td>
<td>22.7</td>
</tr>
<tr>
<td>S-Type</td>
<td>19.1 (8.4)</td>
<td>5.7</td>
<td>32.2</td>
<td>26.5</td>
</tr>
<tr>
<td>RS-Type</td>
<td>23.1 (6.3)</td>
<td>10.8</td>
<td>35.1</td>
<td>24.3</td>
</tr>
</tbody>
</table>

FC = Full Cohort, C7 = Seventh Cervical Vertebra, St-Type = Straight, GK-Type = Global Kyphosis, S-Type = Sigmoidal, RS-Type = Reverse Sigmoidal, SD = Standard Deviation.

5.14.7.2  *Lateral radiographic measures: Conclusion*

Twelve sagittal cervical radiographic measures were performed during this research project. Three radiographic measures including the ATHM, RRA<sub>C2-C3</sub> and RRA<sub>C6-C7</sub> exhibited no significant difference (0.025 to 0.866) between lordotic and non-lordotic groups, whereas the remaining radiographic measures exhibited a significant difference (*p* < 0.004). All radiographic measures, when assessed for intra and inter-rater reliability, demonstrated *Excellent Agreement*.

Findings from this research project suggest the ARA<sub>C2-C7</sub> cannot accurately depict cervical sagittal alignment within non-lordotic curves. Interpreting ARA<sub>C2-C7</sub> data in isolation, without radiographic comparisons, should be conducted with caution, as a single ARA<sub>C2-C7</sub> value can potentially be recorded by any cervical subtype. This research project’s ARA<sub>C2-C7</sub> was similar to published pooled estimates, and a *Very High Positive* correlation was observed between the ARA<sub>C2-C7</sub> and Total RRA. Regardless of the cervical subtype, it is mechanically advantageous to maintain extended segments at C2/3 and C6/7 while the intervening cervical segments are significantly different between groups. The ATHM was not significantly
different between groups, and was slightly larger than the reported value from a standardised lordotic sample. The cohort’s atlas angle was approximately half the value reported from the lordotic sample. Unfortunately, this increased anteriorly translated craniovertebral posture and reduced atlas angle may possibly be the consequence of prolonged static postures adopted while using modern technology.

The full cohort’s mean C0/2 angle is very similar to the literature’s asymptomatic reported values, suggesting this cohort’s upper cervical alignment is similar to previously researched samples. In many aspects the radiographic measures reported from this research project’s full cohort are similar to previously reported asymptomatic mean values. Alarmingly, when segregated into groups, specific non-lordotic subtypes in particular, the GK-type exhibited C0/2 angle and C2 slope values comparable to pre-operative degenerative cervical myelopathic patients. This is critically important given the increasing numbers of non-lordotic subtypes that are being observed in younger populations, and the links between non-lordotic subtypes and numerous degenerative conditions. Future longitudinal research is required to validate the concerns raised in relation to the asymptomatic GK-type values. Understanding the potential timeframe in which these participants possibly develop MSK pathology will become advantageous when developing future proactive treatment strategies.
5.15  Anterior-Posterior Radiographic Measures

5.15.1 Mastoid head tilt angle

Limited reporting of radiographic measures and their protocols is apparent in relation to the cranium’s coronal upright perspective. It is for this reason a decision was made to generate a radiographic head tilt angle by connecting the distal tips of the mastoid processes. This line is referred to as the mastoid line, and an angle is subtended as a horizontal line that transects the distal region of the mastoid line. The mastoid head tilt angle (MHTA) provides radiographic evidence of the head’s orientation in the coronal plane (Figure 5.13). The value of the MHTA is indicated by the side of head tilt (positive values, the distal aspect of the mastoid line is orientated to the right side; negative values, the distal aspect of the mastoid line is orientated to the left side). No statistical data were identified in the literature related to the coronal head tilt angle.

Figure 5.13. The mastoid head tilt angle (MHTA) (superior angle) and the photogrammetric overlayed lateral head tilt angle (inferior angle). A. MHTA left head tilt -1.4°. B. MHTA right head tilt 0.9°, radiographs by Lee Daffin. Anterior/posterior radiographic measures: Results
All statistical analysis was performed on SPSS Viewer Version 22 software package (SPSS Inc., IBM, Chicago, Illinois). Table 5.12 outlines the results of the independent t-tests performed on the two groups (lordotic \( n = 51 \), non-lordotic \( n = 99 \)) for the radiographically determined MHTA (MHTA) and the externally measured LHTA. Levene’s test was applied to assess the equality of variances, and equal variances were assumed in each group across the two measures. A Bonferroni correction was applied to determine the appropriate alpha level for each coronal radiographic measure, \( \alpha = 0.025 \) (0.05/2).

A Pearson correlation was performed to determine the relationship between the MHTA and LHTA for all 150 participants, \( r = 0.815 \), and a High Positive (Mukaka, 2012) was demonstrated between the MHTA and LHTA measures.

Table 5.12. 
Radiographic Measures for the Mastoid Head Tilt Angle and the Externally Measured Lateral Head Tilt Angle, for the Full Cohort and the Two Groups.

<table>
<thead>
<tr>
<th></th>
<th>Mean (SD)</th>
<th>Max Left H/Tilt</th>
<th>Max Right H/Tilt</th>
<th>( p )-value (&lt;0.025)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FC MHTA (°)</strong></td>
<td>0.2 (2.2)</td>
<td>-5.8</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td><strong>Lordotic Group 1</strong></td>
<td>0.0 (2.3)</td>
<td>-3.9</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td><strong>Non-Lordotic Group 2</strong></td>
<td>0.4 (2.2)</td>
<td>-5.8</td>
<td>5.1</td>
<td>0.259</td>
</tr>
<tr>
<td><strong>FC LHTA (°)</strong></td>
<td>0.3 (1.8)</td>
<td>-4.1</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td><strong>Lordotic Group 1</strong></td>
<td>0.0 (2.0)</td>
<td>-4.1</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td><strong>Non-Lordotic Group 2</strong></td>
<td>0.5 (1.7)</td>
<td>-3.8</td>
<td>4.4</td>
<td>0.270</td>
</tr>
</tbody>
</table>

FC = Full Cohort, MHTA = Mastoid Head Tilt Angle, LHTA = Lateral Head Tilt Angle, SD = Standard Deviation, Max: Maximum, H/Tilt = Head Tilt, positive values = Right Side Head Tilt, negative values = Left Side Head Tilt.
5.15.2.1 Anterior-posterior radiographic measures: Discussion

The reported full cohort MHTA and LHTA values from this research project indicate that a horizontal line connecting the tips of the mastoid processes, or the ear lobes, is essentially level when determined on a single radiograph. The range across both measures is less than 6° of head tilt to either the left or right side. Independent t-tests determined no significant differences between groups for both measures, MHTA ($p = 0.259$) and LHTA ($p = 0.270$). A Pearson correlation determined a High Positive relationship between the MHTA and LHTA. This High Positive relationship indicates that the tips of the ear lobes accurately reflect the position of the osseous mastoid process relative to a horizontal line. A High Positive finding also validates the use of either the MHTA or the external measure LHTA to determine coronal head tilt.

5.15.2.2 Anterior-posterior radiographic measures: Conclusion

In conclusion, the mean asymptomatic MHTA and LHTA is fundamentally level. Statistically significant differences are not present between lordotic and non-lordotic groups when assessed by both measures. However, a High Positive correlation is observed between the MHTA and LHTA measures. Craniovertebral balance is maintained close to the horizontal plane when viewed from a coronal perspective, regardless of the sagittal cervical alignment adopted by the participant.
Chapter Five: Answering the Secondary Research Questions

- During radiographic subtype classification, are the different methodologies consistently classifying each subtype, or are potential inter-methodological inconsistencies affecting subtype classification?

As published in the article “The efficacy of sagittal cervical spine subtyping: Investigating radiological classification methods within 150 asymptomatic participants”, inconsistencies were observed between the two commonly used subtype classification methodologies. Descriptive assessment and classification of the cervical subtypes involves identifying and using numerous radiological landmarks to develop an overall impression of the cervical spine’s sagittal alignment. The literature relies on either visual (Herbst, 1980; Takeshima et al., 2002) or numerical (Ohara et al., 2006) methodologies to classify cervical subtypes. It was evident when agreement by chance was considered only a moderate level of agreement was identified, Cohen's kappa coefficient $\kappa = 0.531$ (53.1%).

The two methodologies exhibit bias. The Centroid method (numerical) selects L and St-types over S and RS-types, whereas the modified Takeshima/Herbst method (visual) selects S and RS-types over St-types (Table 5.4 and Table 5.5). Consistency between classification methods appears to be enhanced when there is a greater number of extended (L-type 90.2%) or flexed (GK-type 85.7%) segments in sequence (Table 5.3). Specific differences in the classification guidelines for the non-lordotic subtypes resulted in classification inconsistencies in approximately two-thirds of the participants demonstrating St, S, and RS-types (Figure 5.14). Differing methodological guidelines generating a bias of this magnitude is a concerning limitation.
It appears to be increasingly accepted that habitual postures assumed while interfacing with modern technology are increasing the number of non-lordotic alignment patterns observed within the world’s younger populations. Kang et al. (2012), C. S. Lee et al. (2012), Yukawa et al. (2012) and Fares et al. (2017) all support the viewpoint that suggests modern society may be cultivating a generation that never developed a cervical lordosis to begin with however, at this point the evidence is still limited and further research is required. Adopting a standardised classification system when determining alignment patterns that exhibit St, S, and RS-types will become increasingly important in future research projects and clinical investigations. Correctly classifying cervical sagittal alignment may be less likely when a multi-method approach is undertaken, thus strengthening classification validity. The published findings of this research project will serve as the impetus for this crucial function, and act as the initial baseline from which cervical subtype classification standardisation can progress and develop.
In conclusion, methodological bias is evident, and standardisation is imperative if accurate cervical classification reporting is to transpire in the future. This is important given the increasing numbers of non-lordotic subtypes that are being observed in young populations, and the links between non-lordotic subtypes and numerous degenerative conditions.

- Do the commonly cited radiographic measures of sagittal cervical alignment act as potential indicators of postural control?

As evident when investigating the relationship between EMPA and the underlying cervical vertebral alignment, our research was able to determine that substantial cervical subtype variability is present throughout the full CVA range. At this stage, conclusively validating a single sagittal external measure of postural alignment that reflects the inter-relationship of the underlying cervical vertebral alignment remains elusive. Investigating the relationship between a single external measure, in this case the CVA, and a structural entity that has such enormous inter-segmental and global variabilities, both within and between participants, is virtually unrealistic and impractical. A single figure lacks the flexibility to account for the enormous variability within the structures they overlay, as virtually all 5° CVA ranges investigated exhibited the presence of all 5 classified cervical sub-types (Table 4.4).
A similar obstacle was encountered to this when endeavouring to answer the secondary research question. Establishing a relationship between radiographic measures and postural control that comprises the statistical strength to act as an indicator of postural control is again impractical. Radiographic measures of sagittal cervical alignment are like EMPA - they also lack the flexibility to account for the enormous variability within the structures they overlay. Figure 5.15 represents the contrast of two radiographic measures, being the ARAC2-C7 and the ATHM, between a lordotic and global kyphotic cervical curve. The two distinctly different classified cervical curves exhibited similar ARAC2-C7 measures with a difference only 0.1°; however, the ATHM differed by 36 mm. In contrast, Figure 5.10 identified two similar ATHM derived from a lordotic and global kyphotic cervical curve.

Figure 5.15 exemplifies two important points: (1) practically identical radiographic measures can be exhibited by cervical curves that lie on either end of the curve continuum, and (2) one contrasted radiographic measure can be practically identical between two participants, while another radiographic measure can vary enormously. D. D. Harrison et al. (1996) also suggested concerns when reporting the ARAC2-C7 radiographic measure, as an ARAC2-C7 -15° measure can be generated entirely from C6/7 extension or entirely from C2/3 extension, even though the two curves are distinctly different (Figure 5.16). One concern regarding radiographic measurement is the distance between the points used to generate the measures. The greater distance between the points permits more opportunity for skeletal alignment variability to manifest itself. This enormous inter-segmental and global variability, both within and between participants, has complicated the generation of normative radiographic measurement data within the literature.
In contrast, de Zoete et al. (2017) and Konig et al. (2016) recently investigated the possibility of using one CoP parameter to potentially act as an indicator to identify asymptomatic from pathological participants. de Zoete et al. (2017) determined the differences between asymptomatic and NSNP participants, when comparing postural sway parameters, were extremely small, and as such caution was necessary when interpreting the relevance of comparative results. Konig et al. (2016) suggested the boundaries between asymptomatic and pathological postural sway could potentially serve as a means of identifying pathology. The recent research investigating postural control parameters acting as indicators with the potential of discriminating one group from another is still in its infancy and relatively sparse. The literature suggests further research is required to validate normative and pathological CoP parameter data, permitting comparative boundaries to be established.
Figure 5.15. Radiographic measures contrasting the absolute rotation angle (ARA) C2-C7 and the anterior translation of the head measure (ATHM) between a lordotic and global kyphotic cervical spine. A. Lordotic ARA$_{C2-C7}$ -17.5°. B. Lordotic ATHM 5.2 mm. C. Global Kyphotic ARA$_{C2-C7}$ -17.4°. D. Global Kyphotic ATHM 41.2 mm, radiographs by Lee Daffin.
Considerable complexities exist within the domain of postural control when determining the extent to which postural control parameters inter-relate and compare within the various conditions investigated. While attempting to answer this secondary research question, three commonly used radiographic measures consisting of the atlas angle, C2 slope and C7 slope were correlated with the CoP parameter total excursion (TEx) data established on a compliant surface. The three radiographic measures were selected for correlation as they reflect the alignment of several key vertebrae throughout the cervical region, representing angular measures typically published during radiographic sagittal balance analysis of the cervical spine (Abelin-Genevois et al., 2014; Ling et al., 2018; Smith et al., 2013). The TEx on a CS was selected as this parameter demonstrated the largest range of any parameter measured during this research project. It was considered if a radiographic measure were to act as a predictor of postural control, either individually or in combination, a positive finding was more likely to transpire if the parameter exhibited a large range.
All three measures across the entire cohort (n=150) were correlated with the CoP parameter TEx CS both individually ($r = 0.035 – 0.201$, $p = 0.122 – 0.337$) and in combination ($R$ Squared = 0.041, $p = 0.196$) and exhibited extremely poor and non-significantly correlations.

In conclusion, recent research investigating postural control parameters acting as indicators with the potential of discriminating one group from another have highlighted the technical difficulties associated with this endeavour. It is clear sagittal cervical radiographic measures exhibit enormous inter-segmental and global variability, both within and between participants. It is reasonable to assume the results obtained when correlating radiographic measures with a postural control parameter were influenced by the variability observed within the measures. Therefore, our results suggest it is highly improbable that sagittal cervical radiographic measures, whether correlated either individually or in combination, exhibit the capacity to act as potential indicators of postural control parameters.
Chapter 6

The textual structure of this chapter predominantly constitutes material taken in its entirety from a recently submitted manuscript associated with this research project. The manuscript was submitted to the Journal, Gait and Posture (Reference No: GAIPOS-D-17-01177) on the 18th of December 2017, and its status is “under review”.

Subsequent to the material submitted within the manuscript, a final sub-section within this chapter expands on key aspects identified in Chapter 6 that assists in answering the primary research question. A deeper appreciation strengthens this chapter’s final discussion and conclusion, as the contextual knowledge and research results presented within this chapter are critical to answering the primary research question effectively.

6.1 Manuscript Title

The effect of cervical spine subtypes on center of pressure parameters in 150 asymptomatic participants.

6.1.1 Primary research question

- Do asymptomatic participants exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype, show evidence of decreased postural control?
6.2 Abstract

The aim of this study is to (1) compare and contrast asymptomatic radiographically derived sagittal cervical alignment subtypes with center of pressure (CoP) parameters, and (2) investigate the capacity of CoP parameters to act as novel biomarkers for the detection of early cervical degeneration. A strict asymptomatic inclusion criteria was met by 150 participants. All radiographs were assessed using a multi-method subtype system with participants classified into lordotic and non-lordotic groups. Testing involved participants performing a series of eyes-closed 90 s narrow stance trials standing on both a FS and CS (3 trials per surface). CoP parameters were recorded from a force platform sampling at 100 Hz. Significant differences were found between groups on both surfaces for the anterior to posterior range (FS: $p = 0.013$; CS: $p = 0.023$), TEx (FS: $p = 0.029$; CS: $p = 0.005$) and MVeL TEx (FS: $p = 0.032$; CS: $p = 0.004$). Our data suggest that cervical alignment is a sensitive measure capable of distinguishing between asymptomatic lordotic and non-lordotic participants on both surfaces. This is the first study of its type to compare, contrast and report decreased postural control within an asymptomatic cohort, resulting from radiographically determined cervical lordotic and non-lordotic subtypes. Disparities within asymptomatic CoP parameters may possess the capacity to act as novel biomarkers. These biomarkers may represent an early nervous system transition into a precursor state that could facilitate the development of future NSNP.
6.3 Introduction

Functional postural control is required to maintain and regulate a state of balanced equilibrium. Numerous complex coordinated neurological integrations are necessary to preserve the body’s center of mass over either a static or dynamic BoS (Crétual, 2015; Roijezon et al., 2015; Silva & Johnson, 2013). The excursion of the body’s center of mass relative to the BoS is the measurable criteria referred to as postural sway, representing the body’s small adjustments responsible for maintaining upright equilibrium. Force platform generated CoP parameters are the gold standard when assessing postural control, with minimal excursion between the center of mass and the BoS indicating greater postural control and superior neurological coordination (Crétual, 2015; Paillard & Noe, 2015). Reviews within this domain indicate CoP parameters are used in approximately 60% of the published literature that has assessed postural control (Crétual, 2015; Paillard & Noe, 2015). These reviews highlight that researchers in this domain typically use CoP parameters to differentiate asymptomatic control groups from pathological groups and substantiate the clinical findings of applied postural control interventions.

Two landmark systematic reviews have independently concluded that statistically significant differences exist between the CoP parameters of asymptomatic (control), NSNP and WAD participants (Ruhe et al., 2011; Silva & Cruz, 2013). These two reviews indicate asymptomatic participants have been shown to exhibit greater postural control when compared to both NSNP and WAD participants, while WAD participants have significantly less postural control than the other two cohorts. Accordingly, postural control research has focused on differences between asymptomatic and pathological groups, with limited research investigating postural control in otherwise asymptomatic populations.
Recently researchers have started to assess links between postural conditions and postural control. Importantly, researchers have linked forward head posture, a common postural condition, to decreases in postural control in asymptomatic populations (Kang et al., 2012; J. H. Lee, 2016). Although these two studies quantified postural control using standard CoP assessment techniques, they determined FHP through EPM, an approach that may not provide critical information on the true nature of the underlying cervical vertebral alignment (Oliveira & Silva, 2016). Additionally, gross measures of cervical posture such as those assessed using EPM fail to account for the numerous alternative cervical non-lordotic conditions that can only be classifiable radiologically (Ames et al., 2013; Daffin et al., 2017; D. D. Harrison et al., 1996; Ohara et al., 2006). Importantly, recent evidence indicates that non-lordotic subtypes promote the pathogenesis and rate of progression associated with a multitude of cervical osseous and myelopathic degenerative conditions (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015).

A naturally lordotic alignment in the cervical spine is considered optimal for functionality and health-related quality of life factors (Ames et al., 2013; Nouri et al., 2015; Shahar & Sayers, 2016). Alarmingly, recent research highlighted that non-lordotic subtypes are common within an asymptomatic population of young adults (Daffin et al., 2017; Faline et al., 2007; Le Huec et al., 2015). Therefore, it is tempting to suggest that many of the asymptomatic individuals that have been used as controls in previous studies are likely to also display cervical non-lordotic subtypes. This may explain the subtle differences in CoP parameters that exist within samples of asymptomatic individuals (Kang et al., 2012; J. H. Lee, 2016). The question remains as to whether these changes may be used as novel biomarkers to clinically identify early pathology (Konig et al., 2016).
Accordingly, the purpose of this research is to compare and contrast asymptomatic CoP parameters within radiologically determined cervical lordotic and non-lordotic groups.

6.4 Methods

6.4.1 Study design

This cross-sectional study required participants to attend a radiographic assessment and laboratory postural assessment sessions. Approval was obtained from the institutional Research Ethics Committee (S/14/607), with written informed consent obtained from all eligible volunteers in accordance with the institutional human research ethics requirements.

6.4.2 Participants

The sample consisted of 150 asymptomatic participants aged between 18 and 30 years: 61 males (age - 22.7 ± 3.6; height - 177.5 cm ± 7.1; mass - 79.1 kg ± 14.0) and 89 females (age - 22.5 ± 3.6; height - 166.1 cm ± 6.4; mass - 63.9 kg ± 11.1). Participant eligibility was assessed with a project specific self-reporting questionnaire, SF-36, NDI and a PE as described by Daffin et al. (2017). Approval was obtained from the institutional Research Ethics Committee (S/14/607), with written informed consent obtained from all eligible volunteers in accordance with the institutional human research ethics requirements.
6.4.3 Radiographic procedures, instruments and classification

A single lateral cervical radiograph was taken by the same radiographer and digital capturing unit using established radiological procedures (Daffin et al., 2017; D. D. Harrison et al., 1996). The principal researcher classified all cervical sagittal curves using a multi-method subtype system (Figure 6.1) (Daffin et al., 2017), representing an amalgamation of key classification methodologies (D. D. Harrison et al., 1996; Ohara et al., 2006). The association between non-lordotic subtypes and the biological mechanisms responsible for the pathogenesis of degenerative cervical myelopathy (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015) meant that we clustered subtypes into two groups: (1) lordotic, representing 51 (34%) participants and (2) non-lordotic, representing 99 (66%) participants who did not display a lordotic curve (comprising straight, global kyphotic, sigmoidal, and reverse sigmoidal subtypes [Table 6.1]). Lordotic alignment is considered normal while, straight, sigmoidal and reverse sigmoidal alignment are considered abnormal or potentially pathological and global kyphotic alignment is considered completely pathological (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015).

Figure 6.1. A radiographic representation of the typical alignment patterns observed within each cervical subtype classifications. Group 1: Lordotic (L-type). Group 2: Straight (St-type), Global Kyphotic (GK-type), Sigmoidal (S-type), and Reverse Sigmoidal (RS-type) subtypes, radiographs by Lee Daffin.
Table 6.1.
Radiologically Classified Cervical Subtype Groupings by Sex.

<table>
<thead>
<tr>
<th>Subtype</th>
<th>Male</th>
<th>Female</th>
<th>Participants</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-type</td>
<td>$n = 29$</td>
<td>$n = 22$</td>
<td>$n = 31$</td>
<td>Lordotic</td>
</tr>
<tr>
<td>St-type</td>
<td>$n = 14$</td>
<td>$n = 23$</td>
<td>$n = 37$</td>
<td>Non-Lordotic</td>
</tr>
<tr>
<td>GK-type</td>
<td>$n = 2$</td>
<td>$n = 26$</td>
<td>$n = 28$</td>
<td>Non-Lordotic</td>
</tr>
<tr>
<td>S-type</td>
<td>$n = 4$</td>
<td>$n = 9$</td>
<td>$n = 13$</td>
<td>Non-Lordotic</td>
</tr>
<tr>
<td>RS-type</td>
<td>$n = 12$</td>
<td>$n = 9$</td>
<td>$n = 21$</td>
<td>Non-Lordotic</td>
</tr>
</tbody>
</table>

L-type = Lordotic, St-type = Straight, GK-type = Global Kyphotic, S-type = Sigmoidal and RS-type = Reverse Sigmoidal, $n = $ Number of Participants.

### 6.4.4 Center of pressure data acquisition and postural positioning protocols

A Qualisys motion capture system (Qualisys AB, Gothenburg, Sweden) was used to record ground reaction force data from a 400 x 600 x 83 mm force platform model 4060 - 08 incorporating a 16-bit digital internal amplifier, with embedded calibration information and zero cross-talk between channels (Bertec Corporation, Columbus, USA). The force platform was coupled with an analog amplifier model AM6501 using a fixed gain +/- 5V output (Bertec Corporation, Columbus, USA) sampling at 100 Hz (Moghadam et al., 2011; Ruhe, Fejer, & Walker, 2010; Zok, Mazzà, & Cappozzo, 2008). All six ‘best practice’ procedures for enhancing the reliability of CoP data were implemented (Ruhe et al., 2010). Testing was conducted on both a FS and CS, with 3 trials per surface. The CS consisted of a 100 mm thick piece of high-density foam (Field et al., 2008; Moghadam et al., 2011). Participants stood barefoot in a narrow stance position with their great toes and heels touching so their feet were parallel (Field et al., 2008; Santos, Delisle, Lariviere, Plamondon, & Imbeau, 2008; Zok et al., 2008). Once positioned all instructions were given on a television monitor positioned in front of the participants (Zok et al., 2008).
A trial was terminated if any of the following balance errors were observed: (1) opening eyes during the trial, (2) lifting an arm or arms of the body greater than 45° in any direction, (3) stepping off the platform, (4) stumbling or falling out of position, (5) lifting the forefoot or heel, and (6) failing to normalise the test position in 5 s (Bell, Guskiewicz, Clark, & Padua, 2011). No trials met these criteria. A 60 to 90 s rest period was provided between trials at the end of which participants returned to the force platform and readied themselves for the next trial (Bell et al., 2011; Field et al., 2008; Zok et al., 2008).

6.4.5 Data processing

Data were exported and further processed using standard biomechanical analysis software (Visual3D, C-Motion, Inc. Maryland, USA). Data were filtered using a fourth order zero lag Butterworth filter with a cut off frequency of 10 Hz (Ruhe et al., 2010; Santos et al., 2008). The eight standard CoP parameters that were computed for this study can be seen in Table 6.2 (Paillard & Noe, 2015; Palmieri, Ingersoll, Stone, & Krause, 2002; Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996; Qiu & Xiong, 2015).

6.4.6 Statistical evaluation

Shapiro-Wilk tests for normality showed that none of the CoP parameters were normally distributed. Accordingly, nonparametric tests (Mann-Whitney U) were conducted to assess differences between groups for each surface type. The relative magnitude of the between group differences were quantified using r effect sizes ($Z/\sqrt{n}$), and assessed using the following scale: Trivial < 0.20; Small 0.20; Medium 0.50; Large 0.80 (Rosenthal, 1996). The Wilcoxon Signed Rank test was used to determine differences in CoP parameters between FS and CS types. Statistical analyses were completed using SPSS Viewer Version 22 software package (SPSS Inc., IBM, Chicago, Illinois).
The normalised data indicated there was a significant difference between lordotic and non-lordotic groups for both height (p=0.006) and mass (p=0.041) but not for age (p > 0.05). This can be explained by a larger female population in the non-lordotic group. Further investigation indicated that within each group (lordotic and non-lordotic), the variance in the height, mass, or age did not explain more than 10% of the variance in any of the postural sway variables.
<table>
<thead>
<tr>
<th>Category</th>
<th>Measure</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (mm)</td>
<td>Anterior/Posterior Range</td>
<td>The maximum distance being the smallest and largest values between any two points on the CoP path in the trials A/P time series (Paillard &amp; Noe, 2015; Prieto et al., 1996; Qiu &amp; Xiong, 2015).</td>
</tr>
<tr>
<td></td>
<td>Medial/Lateral Range</td>
<td>The maximum distance being the smallest and largest values between any two points on the CoP path in the trials M/L time series (Paillard &amp; Noe, 2015; Prieto et al., 1996; Qiu &amp; Xiong, 2015).</td>
</tr>
<tr>
<td></td>
<td>Anterior/Posterior Root Mean Square</td>
<td>The square root of the mean of the set of standard deviation values squared within the A/P Range time series (Paillard &amp; Noe, 2015; Palmieri et al., 2002; Prieto et al., 1996).</td>
</tr>
<tr>
<td></td>
<td>Medial/Lateral Root Mean Square</td>
<td>The square root of the mean of the set of standard deviation values squared within the M/L Range time series (Paillard &amp; Noe, 2015; Palmieri et al., 2002; Prieto et al., 1996).</td>
</tr>
<tr>
<td></td>
<td>Root Mean Square Distance</td>
<td>The square root of the mean of the total number of consecutive data points within the A/P and M/L CoP path directions squared within the time series (Qiu &amp; Xiong, 2015).</td>
</tr>
<tr>
<td>Velocity (mm/s)</td>
<td>Mean Velocity Total Excursion</td>
<td>The average velocity of the consecutive points on the CoP path divided by the total time of the trials time series (Paillard &amp; Noe, 2015; Prieto et al., 1996).</td>
</tr>
<tr>
<td>Area (mm²)</td>
<td>95% Confidence Circle</td>
<td>The area of a circle that covers 95% of all CoP positions during the trials time series. The radius of the circle represents the one sided 95% confidence limit generated from the resultant distance of the time series (Prieto et al., 1996; Qiu &amp; Xiong, 2015).</td>
</tr>
</tbody>
</table>
6.5 Results

There were significant between group differences in three of the CoP parameters (Table 6.3). These differences were present on both compliant and firm surfaces. Although not the primary focus of this paper, all of the measured CoP parameters were significantly greater on the CS than on the FS ($p < 0.001$). This finding is principally contributed to the high-density foam acting as an external random perturbator augmenting the neurological complexity required to maintain upright equilibrium.

Table 6.3.
Mean (SD) Center of Pressure Parameters, With Level of Significance (p) and Effect Size (r) for Differences Between Lordotic and Non-Lordotic Groups.

<table>
<thead>
<tr>
<th>Surface</th>
<th>A/P Range (mm)</th>
<th>M/L Range (mm)</th>
<th>A/P RMSq (mm)</th>
<th>M/L RMSq (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS Lordotic</td>
<td>33.6 (7.1)</td>
<td>36.8 (8.7)</td>
<td>9.3 (3.6)</td>
<td>7.4 (1.7)</td>
</tr>
<tr>
<td>FS Non-Lordotic</td>
<td>37.8 (10.9)</td>
<td>37.6 (8.2)</td>
<td>9.6 (3.3)</td>
<td>7.8 (1.8)</td>
</tr>
<tr>
<td>p / r</td>
<td>0.013* / -0.20</td>
<td>0.655 / -0.04</td>
<td>0.462 / -0.06</td>
<td>0.340 / -0.08</td>
</tr>
<tr>
<td>CS Lordotic</td>
<td>58.3 (12.2)</td>
<td>6.4 (11.4)</td>
<td>12.5 (4.0)</td>
<td>10.4 (1.9)</td>
</tr>
<tr>
<td>CS Non-Lordotic</td>
<td>62.7 (10.9)</td>
<td>57.7 (10.9)</td>
<td>12.9 (3.4)</td>
<td>10.7 (2.0)</td>
</tr>
<tr>
<td>p / r</td>
<td>0.023* / -0.19</td>
<td>0.299 / -0.08</td>
<td>0.275 / -0.09</td>
<td>0.754 / -0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface</th>
<th>RMSq Dist (mm)</th>
<th>TEx (mm)</th>
<th>MVeL TEx (mm)</th>
<th>95% CC (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS Lordotic</td>
<td>12.2 (3.6)</td>
<td>1758 (401)</td>
<td>20.9 (4.8)</td>
<td>1287 (719)</td>
</tr>
<tr>
<td>FS Non-Lordotic</td>
<td>12.7 (3.3)</td>
<td>1901 (389)</td>
<td>22.6 (4.6)</td>
<td>1412 (707)</td>
</tr>
<tr>
<td>p / r</td>
<td>0.233 / -0.10</td>
<td>0.029* / -0.19</td>
<td>0.032* / -0.18</td>
<td>0.199 / -0.10</td>
</tr>
<tr>
<td>CS Lordotic</td>
<td>16.5 (3.9)</td>
<td>3167 (822)</td>
<td>37.7 (9.8)</td>
<td>2434 (1129)</td>
</tr>
<tr>
<td>CS Non-Lordotic</td>
<td>17.0 (3.4)</td>
<td>3563 (893)</td>
<td>42.4 (10.6)</td>
<td>2545 (1020)</td>
</tr>
<tr>
<td>p / r</td>
<td>0.400 / -0.07</td>
<td>0.005* / -0.23</td>
<td>0.004* / -0.23</td>
<td>0.338 / -0.08</td>
</tr>
</tbody>
</table>

FS = Firm Surface, CS = Compliant Surface, A/P Range = Anterior/Posterior Range, M/L Range = Medial/Lateral Range, A/P RMSq = Anterior/Posterior Root Mean Square, M/L RMSq = Medial/Lateral Root Mean Square, RMSq Dist = Root Mean Square Distance, TEx = Total Excursion, MVeL TEx = Mean Velocity Total Excursion, 95% CC = 95% Confidence Circle, SD = Standard Deviation, r = effect size, p = p-value, * = Significant Differences, p-value = <0.05.
6.6 Discussion

The key purpose of this research was to compare and contrast asymptomatic CoP parameters within radiologically determined cervical lordotic and non-lordotic groups. To our knowledge this is the first study of its type and represents a new perspective on the potential for CoP parameters to be used as novel biomarkers to clinically identify early transitional pathology. Notably, our sample was selected exclusively on their asymptomatic status, without preconception of their prospective group allocation, making our sample typical for a ‘control group’ within this domain (it is also larger \( n = 150 \) than comparative studies). Finally, rather than focusing on EPM, group allocation was performed radiologically, with ‘best practice’ methodologies incorporated throughout the postural control testing.

Our findings indicate that decreased postural control are associated to non-lordotic subtypes within an asymptomatic sample. Specifically, Small but significant differences in A/P Range, TEx and MVeL TEx were found between subtypes on both surfaces. Research within this domain typically assesses differences between control and pathological groups, with differences in postural control being exaggerated as a function of the underlying pathologies within the symptomatic groups. In our study we were able to identify differences within an otherwise asymptomatic sample, emphasising the sensitivity of the significant CoP parameters for assessing decreases in postural control.
Regardless of the group or surface type all the participants demonstrated comparable postural control within the sway area covered by the 95% CC. While this common measure of postural control has been used to record differences between groups of asymptomatic and pathological samples (Raymakers, Samson, & Verhaar, 2005; Ruhe et al., 2011; Silva & Cruz, 2013), it does not appear to be sensitive enough to determine the influence of cervical subtypes on postural control in an asymptomatic population. Combined, our results show that both the lordotic and non-lordotic subtypes maintain a comparable sway area, but the later have greater A/P Range, TEx and MVeL TEx.

We identified 99 non-lordotic participants radiologically comprising straight, global kyphotic, sigmoidal, and reverse sigmoidal subtypes. Similar studies within this domain have been limited to assessing only FHP determined by EPM (Kang et al., 2012; J. H. Lee, 2016). However, the association between non-lordotic subtypes and the biological mechanisms responsible for a multitude of cervical osseous and neurological degenerative conditions (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015), provides support for the direct assessment of cervical alignment via radiography. A potential limitation can arise when allocating straight, global kyphotic, sigmoidal and reverse sigmoidal subtypes via EPM. Although this gross criterion can characterise postural conditions associated with craniovertebral sagittal plane translation, it fails to determine the precise cervical vertebral alignment. The cervical spine’s sagittal plane translation encourages the different underlying vertebral patterns to develop within every subtype (Ames et al., 2013; D. D. Harrison et al., 1996; Iyer et al., 2016; Nouri et al., 2015). Clearly, the detrimental long-term effects of non-lordotic subtypes warrants greater attention than indirect measures such as EPM. The latter is particularly important in asymptomatic samples, where greater measurement precision is required to accurately allocate participants into correct cervical subtypes.
Due to the asymptomatic samples similarities we suggest concentrating on those CoP parameters shown to be significant (A/P Range, TE\text{x} and M\text{Vel TE}\text{x}) coupled with the sway area (95\% CC). Consolidating the choice of CoP parameters investigated will reduce over representation and enhance reporting consistency (Crétual, 2015), a factor strongly supported when initially developing preliminary novel biomarkers (Konig et al., 2016). Moreover, our data may contribute to the standard CoP descriptors required to develop novel biomarkers capable of identify early pathology. For example, the biological mechanisms associated with NSNP and the pathological predisposition of the non-lordotic state need to be considered. NSNP sufferers display decreased postural control (Ruhe et al., 2011; Silva & Cruz, 2013), and the non-lordotic state promotes degeneration (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015). Accordingly, through continued research, postural control analysis may have the capacity to identify the transitional state within the nervous system that results in individuals developing NSNP. Future research is essential within the asymptomatic postural control domain, to propagate comparable standardised CoP data collection capable of being used to develop clinically valid biomarkers.

6.7 Limitations

A potential limitation of the current study may be the assumptions made from a single lateral cervical radiograph. The cervical spine is highly mobile and so its plausible that several slight natural alignment variants exists during stance. One lateral radiograph of an assumed natural cervical posture is only a representation of the adopted posture at that instant in time, but multiple image analyses are extremely rare in this field. Additionally, the participants adopted a narrow stance position while undertaking all the CoP testing protocols whereas, the participants positioned their feet approximately shoulder width apart while the
radiographs were taken. The narrow stance position adopted during CoP testing protocols may alter the alignment of the cervical spine when compared to that observer radiographically.

6.8 Conclusion

We believe our study is the first to use a multi-method radiographic approach to classify asymptomatic cervical subtypes and identify decreased postural control within a non-lordotic group. Our findings demonstrate that decreased postural control is present in asymptomatic participants across all non-lordotic subtypes and is not isolated exclusively to FHP. Our asymptomatic findings could potentially further the understanding concerning an early transitional phase associated with NSNP. In light of the present findings, the authors believe that A/P Range, TEx, MVel TEx in association with a comparable 95% CC represent the key measures within the asymptomatic domain. The rigorous protocols adhered to throughout this study provide an opportunity for developing a normative database of biomarkers for the early detection of cervical degeneration.

6.9 Key Points

- Asymptomatic cervical non-lordotic subtypes display decreased postural control.
- Three CoP parameters differ between cervical lordotic and non-lordotic subtypes.
- Significant differences were identified on both firm and compliant surfaces.
6.10 Postural Control Sub-Section

The subsequent sub-section expands on certain key aspects identified in Chapter 6. Although identified within the submitted manuscript, several aspects are detailed in greater depth. A deeper appreciation strengthens this chapter’s final discussion and conclusion, as the contextual knowledge and research results presented within this chapter are critical to answering the primary research question effectively.

6.11 Compliant Surface

Moghadam et al. (2011) indicated a CS represents a 10cm thick piece of high-density foam covering the force platform (Figure 6.2). Numerous researchers have concluded that the aim of placing a high-density piece of foam over the force platform during postural control trials is to create a state of "dynamic posturography". While the participant randomly sways and attempts to remain upright, the foam acts as an external random perturbator substantially modifying somatosensory inputs, therefore augmenting the neurological complexity required to maintain upright equilibrium. (Field et al., 2008; Moghadam et al., 2011; Treleaven et al., 2008; Uthaikhup et al., 2012).
6.12 Centre of Pressure Data Acquisition

Maximizing the reliability and enhancing the comparability of the reported CoP data within this research project was an essential requirement. To achieve these goals, this research project implemented the Ruhe et al. (2010) six “best practice” parameters for enhancing the reliability of CoP data in their entirety. The systematic review conducted by Ruhe et al. (2010) suggested conflicting data have been reported over the past 20 years regarding the test-retest reliability of CoP data, and, alarmingly, no standardised protocol for acquiring CoP data in research has been established. Ruhe et al. (2010) reviewed 32 postural control articles to establish the six best practice parameters for enhancing the reliability of CoP data, identifying the following parameters:
• Sampling Frequency: 100 Hz.
• Cut-Off Frequency: 10Hz.
• Duration: 90’s or greater.
• Number of trials: three to five trials.
• Visual Condition: Eyes Closed in all trials.
• Surface: Firm.

Silva and Cruz (2013) commented positively on the six parameters identified by Ruhe et al. (2010), supporting the view that refinement, standardisation of methodologies and parameters enhances the reliability of results, allowing comparisons to be made between future research project results. Silva and Cruz (2013) supported additional comments made by Ruhe et al. (2011) within their systematic review into postural control parameters and symptomatic states that the heterogeneous nature of many studies’ methodologies made inter-study comparisons very difficult. Both these research groups expressed the concern that experimental setup and documentation is often poorly executed within the postural control domain.
6.13 Guidelines for Delivering Participant Instructions

Zok et al. (2008) articulated the importance of standardisation when issuing instructions during postural control trials. The mechanisms involved in issuing the instructions to the participants have the capacity to negatively influence the overall CoP results. Zok et al. (2008) concluded the protocol for issuing instructions should be automated by using a flat screen monitor to visually issue the instructions. Issuing postural control instructions visually standardises the protocol and eliminates the variability in the numerous variables that potentially occur when issuing instructions verbally, for example, voice tone and pitch fluctuations. Interestingly, Zok et al. (2008) identified the contextual organisation of the instructions strongly influences CoP results with “stand as still as possible” producing less variability in CoP parameters than “stand quietly”.

As eluded to throughout this thesis, “best practice” protocols were implemented during every stage of this research project. It was determined that three standardised slides would be developed to issue all postural control trial instructions. The slides were displayed on a 110cm flat screen television monitor situated at eye level, four metres in front of the force platform’s midline. The location of the flat screen television’s support stand was marked on the laboratories floor to standardise repositioning (Figure 6.3). The monitor was connected to a laptop computer via an HDMI cable, and located adjacent to the force platform control computer. The slides’ sequencing was controlled manually by the laptop computer, with their sequencing timed to correspond with the force platform initiation directives.
Figure 6.3. Flat screen television monitor placement in the laboratory, photograph by Lee Daffin.
6.14 Postural Trials Participant Preparation

Detailed sequencing guidelines were provided to all participants prior to any postural control trials. Once the participants assumed the narrow stance position over either the marked central point of the force platform or the foam-covered force platform no verbal communication took place until the conclusion of the postural control trial.

Instructions were issued via three standardised sequenced slides (Figure 6.4):

1. “Stand as relaxed and still as possible” “Look forward with your arms hanging freely for the duration of the trial”.
2. “The trial will begin in five seconds” “Keep your eyes closed during the trial”.
3. “Keep your gaze directed straight-ahead” “Close your eyes now”.

Once the participant achieved a comfortable relaxed natural posture as directed by slide 1, the second slide was displayed. Approximately three seconds after the second slide was displayed, the force platform recording was activated. As soon as the force platform was activated, the third slide was displayed, and the closed eye postural control trial had commenced. At the end of each postural control trial, a computer-generated bell sounded signalling the participant that the trial had concluded. Verbal instructed were then given, asking the participant to “open their eyes and move off the force platform”. A 60 to 90 second rest period was provided between trials at which time the participant returned to the force platform, assumed the narrow stance foot position, and readied themselves for the next trial.
Figure 6.4. The three standardised sequenced slides, illustration by Lee Daffin.

“Stand as relaxed and still as possible”
“Look forward with your arms hanging freely for the duration of the trial”

“The trial will begin in five seconds”
“Keep your eyes closed during the trial”

“Keep your gaze directed straight-ahead”
“Close your eyes now”
6.15 Chapter Six: Answering the Primary Research Question

• Do asymptomatic participants exhibiting conformational cervical subtypes, other than the natural cervical lordotic subtype, show evidence of decreased postural control?

As this question constitutes the primary research question within this research project, the validity of the answer provided is paramount and must be associated with factually sound results. It is important to consider the research methodologies undertaken throughout this entire research project. Every aspect of this research project was conducted with strict adherence to standardised and/or suggested best practice protocols. The sequenced application of the three assessment sessions designated S1, S2 and S3 provided a sound methodological progression to attain valid and reliable data with the capacity to be built upon and applied during subsequent sessions. The robustness of this research project’s entire application indicates the answer to this primary research question will constitute the level of validity currently accepted within the literature, while demonstrating excellent reliability.

The asymptomatic participants were included through a comprehensive written and physical screening process, excluding 32 unsuitable participants. Grouping into either lordotic or non-lordotic subtypes was only initiated following a comprehensive, multi-method sagittal cervical classification protocol. The classification protocol used during this research project, and now constituting a part of the published literature within this domain, is a considerably comprehensive classification protocol, thus strengthening classification validity. Similar radiographic and photogrammetric images were shown to be clinically comparable. Therefore, the radiographic craniocervical alignment was comparable to the best practice photogrammetric protocol for assessing the natural craniocervical posture. The classified subtypes are representative of the alignment patterns adopted by participants while standing.
Accordingly, the accurate quantification of the key CoP parameters measured during this research project were achievable due to the rigorous adherence to the best practice postural control protocols outlined in the literature. This strict protocol adherence permitted significant differences to be established, with asymptomatic participants grouped according to their cervical subtype. Significant differences were exhibited between A/P Range, TEx and MVeL TEx on both firm and compliant surfaces (Table 6.4). Relating these significant differences to what physically transpired on the force platform provides a comprehensive understanding of this research project’s significance.

Table 6.4.
Significantly Different Centre of Pressure Parameters for Lordotic and Non-Lordotic Groups on Both Firm and Compliant Surfaces.

<table>
<thead>
<tr>
<th>Surface</th>
<th>Anterior/Posterior Range (mm) M (SD)</th>
<th>Total Excursion (mm) M (SD)</th>
<th>Mean Velocity Total Excursion (mm/s) M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS Lordotic</td>
<td>33.6 (7.1)</td>
<td>1758 (401)</td>
<td>20.9 (4.8)</td>
</tr>
<tr>
<td>FS Non-Lordotic</td>
<td>37.8 (10.9)</td>
<td>1901 (389)</td>
<td>22.6 (4.6)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.013</td>
<td>0.029</td>
<td>0.032</td>
</tr>
<tr>
<td>CS Lordotic</td>
<td>58.3 (12.2)</td>
<td>3167 (822)</td>
<td>37.7 (9.8)</td>
</tr>
<tr>
<td>CS Non-Lordotic</td>
<td>62.7 (10.9)</td>
<td>3563 (893)</td>
<td>42.4 (10.6)</td>
</tr>
<tr>
<td>p-value</td>
<td>0.023</td>
<td>0.005</td>
<td>0.004</td>
</tr>
</tbody>
</table>

FS = Firm Surface, CS = Compliant Surface, M = Mean, SD = Standard Deviation, p = <0.05.

The mean TEx of non-lordotic asymptomatic participants was 14.2 cm and 39.6 cm greater on both firm and compliant surfaces, respectively. Figure 6.5 diagrammatically represents the conceptual process by which TEx is generated mathematically (Palmieri et al., 2002). To achieve a greater TEx, non-lordotic participants CoM travelled at a greater velocity during the same 90-second period, accounting for the observed significant differences in mean velocity of the TEx. The non-lordotic participants not only travelled further at a faster velocity, they also performed this over a larger A/P range (Figure 6.6).
Figure 6.5. A diagrammatic representation of the total excursion. The total distance travelled between consecutive points of the CoP path length during the duration of the trials time series, adapted from (Palmieri et al., 2002).

Figure 6.6. A diagrammatic representation of anterior/posterior range, representing the maximum excursion being the smallest and largest values between any two points on the centre of pressure path in the trials anterior/posterior time series, (*: centre of mass), adapted from (Kang et al., 2012).
In conclusion, this research project is believed to be the first to use a multi-method radiographic approach to classify asymptomatic cervical subtypes and identify decreased postural control within the non-lordotic group. This research project demonstrated that asymptomatic participants exhibited decreased postural control, and this finding was present in all non-lordotic subtypes on both firm and compliant surfaces. The evidence presented within this thesis has enabled the primary research question to be answered positively. Asymptomatic participants exhibiting conformational cervical subtypes, other than the natural cervical lordotic subtype, do show evidence of decreased postural control.
Chapter 7

Chapter 7 is devoted to discussing this research project in its entirety, primarily drawing on the discussions introduced in Chapters 4, 5 and 6. Unlike the individual chapter discussions, which focused on selected aspects of the research project, this chapter outlines the project from its inception through to the results. This chapter incorporates additional material discussed throughout this thesis, while including pertinent opinions concerning the research project. This chapter does not introduce any new material, rather it provides a cohesive discussion related to this research project’s results. The potential implications these results have on their relevant research domains are briefly explored in this chapter, and then Chapter 8 comprehensively expands on the points raised.

The title of this thesis “The impact of the cervical lordosis on postural sway parameters in asymptomatic participants” indicated the key research domains requiring investigation, and dictated exactly how this research project was developed, designed and then finally implemented. For this research project to progress successfully, three research domains had to come together seamlessly and build progressively on the results obtained during each consecutive testing session. The three primary domains of investigation were (1) asymptomatic participants, (2) cervical sagittal vertebral alignment, and (3) postural control protocols. The foundation of this research project was built on rigorous adherence to standardised protocols while implementing every best practice procedure identified within each relevant domain.
A considerable amount of time and effort was invested into establishing an asymptomatic cohort for the research project. At no point during this research project’s selection procedure was an unsuitable participant permitted to take part; every participant included in this research project was critically and objectively evaluated through a clinically discriminating approach. Kuntz IV et al. (2007) authored a landmark review into asymptomatic radiographic measures used to determined various aspects of sagittal spinal alignment from the occiput to the pelvis. Kuntz IV et al. (2007) stipulated a total of 150 or more asymptomatic participants were required to satisfy their strict inclusion criteria. Accordingly, a figure of 150 participants was chosen as a participant number that would satisfy the requirements of this higher degree by research project, and due to the cohort’s size, the validity of any future positive result should be enhanced.

The selection criteria implemented during this research project were developed and implemented with one key outcome in mind - the successful identification of asymptomatic participants with the capacity to satisfy the stringent criteria set down. The three passive questionnaires were able to exclude 18 participants who did not meet the strict passive inclusion criterion. The active PE served an important role during the inclusion/exclusion procedure excluding 14 participants who did not meet the strict active inclusion criteria. Importantly, incorporating both active and passive selection criteria was crucial in selecting the final asymptomatic sample. If this research project had relied on only passive questionnaires as the mechanism by which inclusion or exclusion was mandated, 14 unsuitable participants would have participated in this research project, therefore tainting the true asymptomatic statues exhibited by the participant undertaking this research project.
The PE was pivotal to this research project, allowing the primary researcher to observe the physical attributes each participant presented while undertaking the clinical tests that constituted the PE. The examination was designed and conducted with an exacting clinical focus; test determination was achieved by the primary researcher’s years of clinical neuromusculoskeletal experience. It is permissible to state with confidence when reflecting on this research project’s inclusion/exclusion criteria determinations that the sample finally selected emulates a true, asymptomatic research sample.

The second research domain that required investigation was cervical sagittal vertebral alignment. A key concern was the ability to accurately represent the underlying cervical sagittal vertebral alignment while the participants adopted a natural upright craniovertebral posture. It was imperative to classify and record the underlying cervical sagittal vertebral alignment appropriately, if we were to determine objectively the impact various cervical sagittal subtypes have on postural control parameters within an asymptomatic cohort. The literature advocated the reliability and validity of photogrammetry when determining a natural upright craniovertebral posture (do Rosario, 2014; Singla; Cohen et al., 2017; Veqar, & Hussain, 2017). The literature suggested photogrammetry was well suited for research or clinical appraisal of the natural upright craniovertebral posture, while data quantification was applicable during the decision-making process (Silva, Punt, Sharples, Vilas-Boas, & Johnson, 2009b; do Rosario, 2014; Singla; Cohen et al., 2017; Veqar, & Hussain, 2017). It was concluded that a natural upright craniovertebral posture established through photogrammetric protocols would ideally serve as a benchmark to act as a point of reference against which future radiographs could be compared.
Evaluating and then comparing measurements determined by two distinctly different imaging methodologies such as photogrammetry and radiography has led to inconsistencies in the literature regarding how well external measures of sagittal postural alignment correlate between the two methodologies (Cohen et al., 2017; do Rosario, 2014; D. E. Harrison et al., 2005; van Niekerk et al., 2008). Following a comprehensive review of the literature, it was decided that comparability could be achieved between the two different image media if stringent adherence to standardised protocols were maintained during both data acquisition and analysis. Image comparability was achieved during radiographic acquisition by attaching steel markers to the identical landmarks used while establishing EMPA photogrammetrically. This research project showed excellent intra- and inter-rater reliability for the external measures of postural alignment, both photogrammetrically and radiographically.

Despite statistically significant differences in all EMPA when quantified using these two distinctly different imaging methodologies, the mean differences ranged from only 0.2 to 1.4 degrees. Differences of such a small magnitude are unlikely to be clinically meaningful as the differences are of a similar value to the identified photogrammetric MDC values. Therefore, these small differences between the two methods are clinically undetectable with any level of certainty. This research project found that external measures determined radiographically were clinically comparable to identical external measures derived from the benchmark used clinically to determine a natural upright craniovertebral posture. Once clinical comparability was established between the photogrammetric and radiographic images, a pivotal point in this research project had been reached.
Radiographic clinical comparability to a known protocol used when establishing natural upright craniovertebral postures allowed this research project to classify the cervical sagittal vertebral alignment adopted by participants during natural upright stance. This step was a very significant point for two reasons: the participant’s cervical subtype could be determined and compared accurately to their CoP postural control parameters. Furthermore, an identified limitation within the literature could be investigated for the first time (Oliveira & Silva, 2016). Doubts remain and have been raised by key researchers in this domain concerning the validity of external measures of postural alignment, particularly the CVA, because it is unclear whether these measures are representative of the vertebral alignment of the underlying cervical spine (do Rosario, 2014; Oliveira & Silva, 2016). Notably, the CVA is reported commonly throughout the literature describing the inclination of the head with respect to the lower cervical spine (Mo et al., 2013). An angle less than 50° is often used to indicate the presence of FHP (Ruivo et al., 2014). This research project identified that 25 (37.3%) participants with a CVA ≤ 50° exhibited a normal lordotic cervical alignment, whereas of the 83 participants with a CVA ≥ 50°, 57 participants (67.5%) displayed a non-lordotic cervical alignment representing all possible subtypes. Substantial cervical subtype variability is present throughout the full CVA range, resulting from the inter-segmental and global variabilities both within and between participants. Unfortunately, at this stage conclusively validating a single sagittal external measure of postural alignment that reflects the inter-relationship of the underlying cervical vertebral alignment remains elusive. Photogrammetric CVA measures demonstrate the capacity to quantify and characterise postural conditions associated with craniovertebral sagittal plane translation with high levels of precision and reliability; however, it fails to determine the precise cervical vertebral alignment. Our findings do not support this notion that photographs are valid and reliable indicators of the underlying spinal shape while standing.
The literature identified two predominant methods typically used during the classification of cervical sagittal vertebral alignment (Herbst, 1980; Takeshima et al., 2002; Ohara et al., 2006; Ruangchainikom et al., 2014). The two classification methods used markedly different techniques to classify sagittal vertebral alignment. One method relies on visual interpretation (Herbst, 1980; Takeshima et al., 2002), while the other method determines the curve classification by numerical indicators (Ohara et al., 2006; Ruangchainikom et al., 2014). The only relationship the two methods encompass is the actual curves they are endeavouring to identify. The literature does not specify which method is the most appropriate to use when reporting the cervical subtype, and this ambiguity presented a conundrum. Cervical spine subtype classification methods must be reliable, interchangeable, and reduce bias (Janusz et al., 2016; Ohara et al., 2006). There was only one logical approach this research project could take to effectively overcome this problem. It was decided that both methods would be applied independently to classify each participant cervical subtype, and then following classification, the selected subtypes determined through each method would be compared for all 150 participants.

Preceding classification by each method, the selected subtypes were compared for each participant. Unfortunately, a worrying finding ensued as both methods display bias. The Centroid method has the propensity to select straight-types over sigmoidal and reverse sigmoidal-types, whereas the modified Takeshima/Herbst method selects sigmoidal and reverse sigmoidal-types over straight-types. Comparisons between the selected cervical subtypes indicated that classification inconsistencies occurred on 56 occasions, a finding that was unacceptable. The three factors responsible for most of the inconsistencies in subtype classification were: (1) segmental flexion (their number, location, and degree), (2) the large segmental extension angles located at the upper (C2/3) and lower (C6/7) sub-axial spine, and
(3) the sigmoidal and reverse sigmoidal-type transitional region (either C3/4, C4/5 or C5/6) between the upper and lower sub-axial cervical curves.

Classification inconsistencies of the magnitude identified between the two methods had to be resolved with a methodology consistent with the strict adherence to the standardisation adopted throughout every aspect of this research project. The biases identified between the two methods protocols prompted an additional review of the relevant literate in conjunction with the two methods’ selection guidelines. It was determined that in cases of inconsistency, the RRA flexion or extension measures from C2/3 to C6/7 were to be performed and contrasted with each method’s guideline. A classification decision was reached when the collective methodological guidelines and RRA evidence supporting the selection of one method’s subtype could not be refuted by the alternative. The combination of extended and flexed cervical segments, within a region of the vertebral column that should predominately exhibit extension, contribute to the moderate level of classification inconsistencies observed between the two methods.

This multi-method sagittal cervical subtyping classification protocol permitted the selection of a justifiable cervical subtype to represent each of the 150 participants’ cervical sagittal vertebral alignment. The findings related to this multi-method sagittal cervical subtyping classification protocol were accepted for publication by the Journal of Craniovertebral Junction & Spine in late 2017. It is suggested that this multi-method approach be adopted by future researchers aspiring to publish cervical classification results. Adoption of this approach should increase reliability, validity, and cross-correlation of clinical and research findings. The problem of inconsistency was approached with the best available evidence within the literature (Herbst, 1980; D. D. Harrison et al., 1996; Takeshima...
et al., 2002; Ohara et al., 2006; Ruangchainikom et al., 2014; Janusz et al., 2016), and this recognition provides assurance that this research project had applied and adhered to all the best practice recommendation within the domain of cervical subtyping.

Participants were segregated into two groups according to their cervical subtype; the first group contained participants who exhibited a lordotic subtype \((n = 51)\), while the remainder constituted the non-lordotic group \((n = 99)\). This was the first point at which the research project retained two individual groups selected due to a physical characteristic, that being their cervical sagittal subtype. This point placed the research project in a unique position - until group allocation, all 150 participants had been selected exclusively on their asymptomatic status. Participant selection was conducted without preconceptions of prospective group allocation, therefore this research project’s cohort is a typical representation for a ‘control group’ within this domain.

Clearly, the detrimental long-term effects of non-lordotic subtypes (Ames et al., 2013; Nouri et al., 2015) warrants greater attention than indirect EMPA to determine the relationship between cervical alignment and postural control (Kang et al., 2012; J. H. Lee, 2016). Cervical classification precision was required, therefore the key purpose of this research project was to compare and contrast asymptomatic CoP parameters within radiographically determined cervical lordotic and non-lordotic groups. As with every aspect of this research project, postural control trials were conducted with the same rigorous adherence to standard protocols and suggested best practice procedures. The initial surface type chosen to perform the postural control trials was a random allocation to either the firm or CS followed by the alternative surface type, while 3 consecutive 90 second trials were performed on each surface.
Notably, while the postural control trials were being conducted, the classification inconsistency conundrum had not been resolved satisfactorily. Therefore, the primary researcher was essentially blinded as to which group most of the participants would finally be allocated. This aspect of the research project’s data collection phase indicates the impartial nature in which the CoP postural control data were acquired. It was not the intention of this research project to blind the primary researcher, it was an artefact resulting from the methodological classification inconsistencies. At the completion of the 150th postural control testing session, the cohort’s data were exported and further processed using standard biomechanical analysis software allowing the eight standard CoP parameters assessed to be computed for this research project. Statistical analyses were completed to determine differences in CoP parameters between both groups for the firm and CS types.

The statistical analyses provided the specific result this research project was established to investigate. Meticulous development, planning, methodological re-evaluation when required, consistent implementation of identical standardised testing protocols and stringent adherence to accurate data processing methods at every stage of the research project established significant differences. These differences were established in three of the eight CoP parameters assessed during this research project. The three parameters that exhibited significant differences between lordotic and non-lordotic participants did so on both firm and compliant surfaces alike. Specifically, small but significant differences were exhibited in the A/P Range, TEx and MVeL TEx. All participants demonstrated comparable postural control within the sway area covered by the 95% confidence circle (95% CC). This measure commonly identifies differences between groups of asymptomatic and pathological samples (Raymakers et al., 2005; Ruhe et al., 2011; Silva & Cruz, 2013), yet it does not appear to be sensitive enough to determine the influence of cervical subtypes on postural control in an asymptomatic population.
Physically, non-lordotic participants travel a greater tangible distance (excursion length) during their 90 second trials, and achieving this result requires significantly greater velocity. The greater excursion length was significant within the A/P Range. The ability to identify significantly different CoP parameters between lordotic and non-lordotic participants equates to the identification of an objective decreased postural control capability within the asymptomatic non-lordotic group’s CNS integration capacity. Asymptomatic samples, by their definition, maintain considerable similarities, therefore consolidating the choice of CoP parameters investigated to those shown to be significant (A/P Range, TEx and MVel TEx), coupled with the sway area (95% CC), may reduce over representation and enhance reporting consistency (Crétual, 2015). The evidence presented within this thesis has enabled the primary research question to be answered positively: asymptomatic participants exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype, do show evidence of decreased postural control.

Studies reporting increases in the number of people displaying non-lordotic subtypes within asymptomatic adolescent, young adult and adult populations (Faline et al., 2007; Le Huec et al., 2015; C. S. Lee et al., 2012) were supported by the finding of this research project (Daffin et al., 2017). Alarmingly, this increase in non-lordotic subtypes may well have implications for the pathogenesis and rate of progression associated with cervical degenerative conditions (Ames et al., 2013; Nouri et al., 2015). The aspiration of this research project was the objective identification of neurological alterations within asymptomatic participants who presented radiographically with cervical non-lordotic spinal alignment. Having achieved this goal, these positive results may provide future researchers with an initial research platform to investigate the most relevant clinical point, to implement rehabilitation strategies designed to improve decreased postural control parameters in asymptomatic individuals.
Research within the postural control domain typically assesses differences between asymptomatic (control) and pathological groups, with differences in postural control being exaggerated as a function of the underlying pathologies within the symptomatic groups. In our study we were able to identify differences within an otherwise asymptomatic sample, emphasising the sensitivity of the significant CoP parameters for assessing decreases in postural control. Moreover, our data may contribute to and stimulate future research endeavours investigating and developing biomarkers capable of identify early pathology using differences in standard CoP descriptors (Konig et al., 2016). The biological mechanisms associated with NSNP, and the pathological predisposition of the non-lordotic state, need to be considered. NSNP sufferers display decreased postural control (Ruhe et al., 2011; Silva & Cruz, 2013), and the non-lordotic state promotes degeneration and increased pain syndromes (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015). Accordingly, through continued research, postural control analysis may have the capacity to identify the transitional state within the nervous system that results in individuals developing NSNP. The concept of clinically valid biomarkers is discussed in detail within the following chapter.

A potential limitation of the current study may be the assumptions made from a single lateral cervical radiograph. The cervical spine is highly mobile and so it’s plausible that several slight natural alignment variants exist during stance. One lateral radiograph of an assumed natural cervical posture is only a representation of the adopted posture at that instant in time. The reliability and validity of to assess posture using observation is problematic.
Chapter 8

8.1 Future Applications and Research Directions

In considering the possible future applications and research directions concerning the findings established during this research project, the final chapter of this thesis explores literature associated with, and related to, these possible applications. All discussions involving any future applications are based on the information published within the current domain-appropriate literature. The findings of this research project have identified that asymptomatic participants exhibiting conformational cervical subtypes, other than the natural cervical lordotic subtype, do show evidence of significantly decreased postural control. The objective findings established during this research project serve as the impetus for discussions involving possible future applications and/or research directions.

The findings identified in this research project are novel. They represent the first instance of a finding of this nature being described in detail. The findings were acquired through a new and unique methodological perspective with the capacity to determine, segregate and report postural control parameters within distinct cervical subtypes within asymptomatic participants. As such, the primary focus of any future applications and/or research directions should initially encompass independent research that substantiates these findings. Assuming reliability is established, findings of this nature should also be independently validated over the course of time.
The novel nature of these findings dictates neither reliability nor validity has been established, therefore all future applications and/or research directions covered in this chapter are considered as general discussions representing the views of the primary researcher following a review of the relevant literature within the domain-appropriate areas.

Three secondary research questions, listed below, have been raised that reflect possible future applications and/or research directions. The first two secondary research questions discuss the capacity of CoP being employed as biomarkers to identify future pathological changes prior to symptomatic presentation. The third secondary research questions investigate the possible mechanisms responsible for the postural control results obtained by this research project.

- In an asymptomatic sample, is the level of postural control within a cervical non-lordotic sample similar to those established in NSNP samples during comparable testing protocols?
- Is the reliability of the current CoP collection protocols amenable when formulating potential novel baseline biomarkers, that retain the capacity of being incorporated into a theoretical longitudinal study designed to identify possible early clinically cervical pathology?
- If asymptomatic participants exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype show evidence of maladaptive decreased postural control, how does the literature clarify a potential positive finding?
During the development of this research project, one underlying intention was always clear. Following a possible positive result, could the identified CoP parameters and protocols translate into a clinical protocol with the potential to identify NSNP sufferers prior to the development of symptomatic syndromes. Considering the alarming increase in non-lordotic subtypes within the younger population (Daffin et al., 2017; C. S. Lee et al., 2012), and the association these subtypes have with the pathogenesis and rate of progression in many cervical degenerative conditions (Ames et al., 2013; Nouri et al., 2015), the underlying intention of this research project requires an insightful discussion. The positive findings identified during this research project now permit this general intention to be theroretically explored.

While endeavouring to answer the first two secondary research questions, consideration is given to the precise relationship this research project’s positive findings have with the relevant domain-appropriate literature. The two secondary research questions are investigated and discussed separately. The two questions are, to a certain extent, interrelated, therefore a concluding discussion bring this pertinent information together allowing greater transparency regarding possible future applications and/or research directions related to the use of CoP parameters as biomarkers. When considering potential answers to the raised research questions involving future applications and/or research directions, presumptions based on our current knowledge are inferred. To assist in this process, applicable information is concisely re-introduced to establish a contextual basis which will permit structured, insightful discussions.
8.2 Current Perspectives Regarding Postural Control Comparability

Stergiou, Harbourne, and Cavanaugh (2006) conferred that a natural and normal characteristic of human postural control is variability, and they proposed that an optimal, healthy level of physiological variability exists. Stergiou et al. (2006) suggest that postural control variability is highly complex, with alternative describable forms of variability existing on either end of the variability continuum. An overly rigid (unchanging) physiological system has reduced levels of variability, whereas an unstable (noisy) physiological system exhibits increased levels of variability. These two variability descriptors reside on either end of the variability continuum, while the optimal healthy level of physiological variability is located centrally. Traditional views on movement variability propose higher levels of variability are detrimental and are customarily contributed to pathological conditions. Reduced levels of postural control variability representing pathological conditions are relatively elusive and scantily reported in the literature (Konig et al., 2016).

Regardless of which end of the continuum is investigated, it is thought that both ends have an inadequate capacity to modulate an appropriate physiological response associated with either internal or external movement fluctuations (Konig et al., 2016; Stergiou et al., 2006). At the most fundamental level, comparability between two CoP parameters derived independently on similar samples by two research groups should represent a simple objective, quantitative task that results in an appropriate representative outcome. Unfortunately, it is not as simple as one would expect. Essentially CoP parameters are derived through recording movement variability, and this variability can lie anywhere along its continuum.
Accurate measurement comparability requires initially understanding the optimal upper and lower boundaries for each specific condition to be compared. Optimal boundaries can only be established through the application of identical protocols on samples with similar demographics. Establishment of pathological boundaries is only permissible when CoP data comparability is performed between similar pathological conditions. The optimum CoP boundaries between physiological and pathological movement can only be compared accurately and satisfactorily when the preceding prerequisites transpire. It has been substantiated that neuromusculoskeletal pathologies associated with the craniocervical region, such as NSNP and WAD, exhibit decreased postural control when compared to those of asymptomatic participants (Ruhe et al., 2011; Silva & Cruz, 2013). The boundaries of NSNP must be accurately defined through the incorporation and implementation of standardised CoP protocols that comprise several key areas including the metrological characteristics of the instruments, comparable data acquisition and statistical analysis protocols.
8.3 Responding to the First and Secondary Research Questions

- In an asymptomatic sample, is the level of postural control within a cervical non-lordotic sample similar to those established in NSNP samples during comparable testing protocols?

There are several issues that have been raised regarding the ability to compare CoP results between research projects. Stergiou et al. (2006) pondered the nature of movement performance variability and its optimal boundaries, considering they remain uncertain and may not exist. Ruhe et al. (2010) indicated the domain of postural control has failed to implement a standardised protocol for acquiring comparable CoP data. This lack of standardisation has resulted in conflicting CoP data being reported while test-retest comparability and reliability are almost unobtainable.

The numerous individual studies we identified within the literature were conducted through the application of a domain-appropriate scientific method; however, methodological standardisation is non-existent. Following this realisation and given a desire to improve CoP comparability, Ruhe et al. (2010) published the six “best practice” parameters for enhancing the reliability and comparability of CoP data. Ruhe et al. (2011) and Silva and Cruz (2013) have both emphasised that the heterogeneous nature of many studies within the postural control domain limits inter-study comparisons. Silva and Cruz (2013) are prominent researchers within the domain of postural control, and these researchers advocated strongly for the attempt by Ruhe et al. (2010) to standardise the CoP acquisition protocol as a way to improve future comparability.
Regrettably, these concerns add a significant level of complexity to any possible answer given to the first of the two secondary research questions. Decades of non-standardisation while collecting CoP data has prevented researchers from simply comparing results against one another. For this reason, it is very difficult at this time to simply compare our research project’s non-lordotic CoP results with the results obtained from research projects that investigated CoP parameters in NSNP participants of a similar age. As this research project endeavoured to implemented “the best practice” postural control protocol available within the literature to date, comparisons with previous CoP results are fraught with potential inaccuracies.

The complexity of simply comparing results goes far beyond standardising the protocol required to acquire CoP data. Accurate comparability of CoP parameters requires the consideration of several additional factors, including but not limited to:

- The samples’ age and sex demographics.
- Inclusion and exclusion criteria for both asymptomatic and NSNP samples.
- Particular CoP parameters investigated.
- Guidelines for delivering participant instructions.
  - visual monitors, size, distance to participant and orientation to force platform.
  - the instructions issued, number of slides, sequencing and timing.
- Time allowed between trials.
- Standardisation of the stance position.
- Standardised high-density foam if performing CS trials.
- Style of clothing worn during the trials.
- Number of individuals in the laboratory during the trials.
• Measurement errors, including but not limited to the metrological characteristics of the instrument used to collect the data.

Any one of these identified additional factors, whether in isolation or combination, may have the potential to influence the results obtained during postural control trials. Therefore, the capacity to compare results may be detrimentally affected by many more factors than simply the six “best practice” parameters identified by Ruhe et al. (2010). Konig et al. (2016) recently contemplated an identical question related to the ability to compare postural control variability between asymptomatic and clinical cohorts. The scope of this manuscript was the possible identification of an optimal level of movement variability between normal physiological and pathological movement. The authors did not detail instrumentation or methodological protocols concerned with the acquisition of CoP data.

Konig et al. (2016) investigated the possibility of identifying the boundaries between physiological and pathological movement. They sought to identify the capacity to distinguish the difference between dissimilar groups through establishing upper and lower limits within normative (asymptomatic) CoP parameters, to ascertain an ideal window of comparable movement variability. The systematic review and meta-analysis conducted by Konig et al. (2016) concluded that while reviewing copious conceptually similar studies, the actuality of determining an optimal normative level of movement variability (upper and lower boundaries), with the capability of distinguishing differences between physiological and pathological groups during quiet stance, is tenuous at best and remains elusive. The current views expressed within the literature indicate that a definitive answer to the first of the secondary questions in not forthcoming.
This research project reported decreased balance control in non-lordotic subtypes using all the best practice CoP acquisition protocols. Research that has implemented identical CoP acquisition protocols and reported either physiological and/or pathological (NSNP) CoP parameters has not be conducted or reported to date. Comparability between this project’s CoP parameters and NSNP CoP parameters reported by an independent research project is not achievable.

In conclusion, this question is unable to be answered with any degree of certainty. If an attempt was made to answer this question with a CoP value, it would be purely speculative on the basis that no comparable evidence exists presently. We propose that in time the non-lordotic CoP parameters reported in this research project will be shown to lie between the lordotic and NSNP CoP data. It is presumptive to suggest that the upper boundaries of the non-lordotic CoP parameters will reside within the lower boundaries of the NSNP CoP parameters once established (Figure 8.1). At this point in time given the available evidence, answering the first of the secondary research questions would have to signify that comparable evidence is currently not available, and as such, this research project’s non-lordotic CoP data cannot be compared to NSNP CoP data.

Figure 8.1. Presumptive diagrammatic interpretation for the center of pressure parameter comparability between the cervical lordotic, non-lordotic and non-specific neck pain samples, illustration by Lee Daffin.
8.4 Responding to the Second, Secondary Research Questions

- Is the reliability of the current CoP collection protocols amenable when formulating potential novel baseline biomarkers, that retain the capacity of being incorporated into a theoretical longitudinal study designed to identify possible early clinically cervical pathology?

Recently, Konig et al. (2016) investigated the potential to use a CoP parameter as a novel biomarker with the ability to differentiate physiological and pathological participants. Konig et al. (2016) reviewed 46 conceptually similar postural control studies totalling 1118 pathological participants aged 59.4 ± 10.2, and 1086 asymptomatic (control) participants aged 58.8 ± 12.1. It was determined that sway area was the most commonly reported CoP parameter across 26 (54%) of the reviewed studies. The sway area was determined with the participants’ eyes open in 44 studies (91%), while 41 studies (89%) reported their standing trials lasted ≥ 30 seconds in duration. Konig et al. (2016) determined with a precision of 60% that the sway area’s lower threshold was 62 mm², while the upper threshold was 265 mm². Konig et al. (2016) strongly suggested that sway areas within these boundaries could possibly distinguish asymptomatic from pathological sway parameters, as pathology had an overall positive effect on postural control exhibiting a significant effect size of 0.8 and larger sway areas.
It would appear the study conducted by Konig et al. (2016) identified three important issues: (1) the heterogeneous nature within the copious, conceptually similar reviewed studies permitted Konig et al. (2016) to determine asymptomatic boundaries with a precision of only 60%, (2) the threshold boundaries reported are specific to the age demographic specified, and are not able to be transferred to any other population, and (3) the capacity to potentially determine threshold boundaries for CoP parameters with the capability of distinguishing asymptomatic participants from those with pathology is achievable.

Following an extensive search of the current literature within this domain, it would appear that the study conducted by Konig et al. (2016) was the first to report a threshold boundary for a single CoP parameter. This study emphasises the complexities associated with this endeavour. de Zoete et al. (2017) followed with a systematic review and meta-analysis investigating the postural sway area in both asymptomatic (healthy) and nonspecific (idiopathic) neck pain participants. de Zoete et al. (2017) reviewed 10 studies with participant numbers ranging from 9 to 107, with participants aged between 18 to 53. The pooled sway area data were formulated into lower and upper boundary limits for both groups during eyes open and closed trials (Table 8.1). The meta-analyses conducted by de Zoete et al. (2017) were unable to demonstrate significant differences between the groups during either eyes open or closed trials (Figure 8.2). de Zoete et al. (2017) speculated that several key aspects likely contributed to their findings: the relatively small number of viable studies, the comparatively large variability reported in the NSNP sway area, and the heterogenous nature of the CoP acquisition protocols. Interestingly, individual studies within this review and meta-analysis showed statistically significant differences between the asymptomatic and NSNP groups.
Table 8.1. Asymptomatic and Non-specific Neck Pain Participants Pooled Sway Area Boundaries for Eyes Open and Closed Trials (de Zoete et al., 2017).

<table>
<thead>
<tr>
<th>Studies Range (n = 9 to 107)</th>
<th>Asymptomatic Participants</th>
<th>Non-Specific Neck Pain</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Limit</td>
<td>Upper Limit</td>
<td>Lower Limit</td>
</tr>
<tr>
<td>Eyes Open</td>
<td>350mm²</td>
<td>660mm²</td>
<td>485mm²</td>
</tr>
<tr>
<td>Mean (4 Studies)</td>
<td>436mm²</td>
<td></td>
<td>768mm²</td>
</tr>
<tr>
<td>Eyes Closed</td>
<td>274mm²</td>
<td>1090mm²</td>
<td>251mm²</td>
</tr>
<tr>
<td>Mean (6 Studies)</td>
<td>653mm²</td>
<td></td>
<td>884mm²</td>
</tr>
</tbody>
</table>

n = Number of Participants, p = <0.05.

Figure 8.2. Postural sway area parameters between non-specific neck pain and asymptomatic participants for eyes open and closed, adapted from (de Zoete et al., 2017).
de Zoete et al. (2017) aimed to identify, then quantify, differences between asymptomatic and NSNP participants using postural control testing to potentially discriminate between the two groups. As such the de Zoete et al. (2017) systematic review appears to be the first study to publish pooled NSNP sway area parameters, with the primary goal of discriminating between asymptomatic and NSNP participants. However, de Zoete et al. (2017) unfortunately encountered the identical issue confronted by Konig et al. (2016) while formulating their pooled threshold limits, that being the heterogenous nature of the studies’ CoP acquisition protocols. de Zoete et al. (2017) concluded limitations are present when reporting pooled CoP parameters due to protocol uncertainties concerning insufficient standardisation and validity.

In conclusion, the second of the secondary research questions must be addressed. As with the answer to the first of the secondary questions, answering the second of the secondary questions is done using a similar approach. Yes, there is clear preliminary evidence that CoP analyses could be used to assist in formulating biomarkers that could serve the function of clinically identifying early cervical pathology. Unfortunately, given the evidence published by Konig et al. (2016) and de Zoete et al. (2017), the validity of using a CoP parameter such as sway area as a biomarker is not at a level that is acceptable. The heterogeneous nature of all the postural control studies reviewed by these two research groups has reduced the likelihood of satisfactorily determining upper and lower boundaries that are rigorous enough to be applied freely to CoP data with any degree of certainty. Therefore, the only reasonable answer to the question concerning CoP parameters acting as biomarkers with the ability to identify early cervical pathology is; its problematic due to the absence of a CoP data base derived from standardised CoP acquisition protocols.
8.5 **Standardised Comparability, Validating Biomarkers and Future Research Directions: Investigating and Discussing the First Two Questions Interrelated Nature**

The first two secondary research questions (re-listed below) associated with the future applications and/or research directions have been discussed and answered independently; however, as alluded to previously, these two secondary research questions are theoretically interrelated. Therefore, the subsequent discussion will examine these two questions within an interrelated contextual premise, and as such will present a structured discussion incorporating a singular response. As this discussion involves future applications and/or research directions, evidence-based presumptions regarding certain matters may be raised as comprehensive relevant literature is currently limited.

- In an asymptomatic sample, is the level of postural control within a cervical non-lordotic sample similar to those established in NSNP samples during comparable testing protocols?
- Is the reliability of the current CoP collection protocols amenable when formulating potential novel baseline biomarkers, that retain the capacity of being incorporated into a theoretical longitudinal study designed to identify possible early clinically cervical pathology?
Several research groups, in particular Ruhe et al. (2011), Silva and Cruz (2013), Konig et al. (2016) and de Zoete et al. (2017), have alluded to the complexities associated with attempting to compare inter-research results from within the postural control domain due to their heterogeneous nature. The recent research published by de Zoete et al. (2017) is considered to represent the only published literature review and meta-analysis that has attempted to compare asymptomatic and NSNP participants. Therefore, it was deemed appropriate to attempt to compare the results of this research project to the findings reported by de Zoete et al. (2017). From the onset of this task it appeared difficulties were inevitable, this research project’s age ranged from 18 to 30 years, whereas de Zoete et al. (2017) quantified their findings from participants age 18 to 53. Advancing age in known to negatively affect CoP postural control parameters (Abrahamova & Hlavacka, 2008; Ekdahl et al., 1989; Era et al., 2006; Rossiter et al., 2017), consequently this single factor places doubt into the comparability of the aforementioned CoP data.

Of concern during this comparative procedure were several additional factors that had the potential to diminish successful comparability, including the feet positioning protocol, a failure to report the mean duration of trials in seconds, number of trials and possible surface types tested (de Zoete et al., 2017). Additionally, the pooled CoP sway area reported by de Zoete et al. (2017) is calculated differently from the 95% CC used to express sway area in this research project (Table 8.2). The task of objectively comparing only one CoP parameter from this single research project to a systematic review’s pooled CoP data was tenuous and problematic. The identified differences outlined in a theoretical context while answering the first two secondary research questions individually are now practically demonstrated with the following example. This example signifies the difficulties involved in directly addressing the answers to the first two secondary research questions with any degree of certainty.
Table 8.2. 
Eyes Closed Sway Area Comparability Between Asymptomatic (Subtypes) and Non-Specific Neck Pain Participants.

<table>
<thead>
<tr>
<th>Eyes Closed</th>
<th>Asymptomatic Participants ($n=298$)</th>
<th>Non-specific Neck Pain ($n=285$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>de Zoete (2017)</td>
<td>Lower Limit</td>
<td>Upper Limit</td>
</tr>
<tr>
<td></td>
<td>274mm$^2$</td>
<td>1090mm$^2$</td>
</tr>
<tr>
<td>Mean SA</td>
<td>653mm$^2$</td>
<td>884mm$^2$</td>
</tr>
<tr>
<td>95% CC</td>
<td>Firm Surface (n=150)</td>
<td>Compliant Surface (n=150)</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Full Cohort</td>
<td>358mm$^2$</td>
<td>4065mm$^2$</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>1369mm$^2$ (711)</td>
<td>2511mm$^2$ (1059)</td>
</tr>
<tr>
<td>Lordotic</td>
<td>358mm$^2$</td>
<td>3926mm$^2$</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>1287mm$^2$ (719)</td>
<td>2434mm$^2$ (1129)</td>
</tr>
<tr>
<td>Non-Lordotic</td>
<td>439mm$^2$</td>
<td>4065mm$^2$</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>1412mm$^2$ (707)</td>
<td>2545mm$^2$ (1020)</td>
</tr>
</tbody>
</table>

SA = Sway Area, 95% CC = 95% Confidence Circle, SD = Standard Deviation, n = Number of Participants.

Table 8.2 is a direct attempt at comparing this research project’s 95% CC data with the pooled sway area data reported by de Zoete et al. (2017). Notably, this research project did not identify significant differences between the lordotic and non-lordotic groups on either the firm ($p = 0.199$) or compliant ($p = 0.338$) surfaces for the 95% CC. It is for this reason that the full cohort’s data will be the only data used during the comparative procedure. Irrespective of the surface type, the initial appraisal of the mean data presented from this research project indicated values that were considerably greater in every respect to the mean pooled data reported by de Zoete et al. (2017) for both asymptomatic and NSNP participants. To determine a valid reason for such a large difference, several articles that constituted the pooled data were identified and investigated.
Michaelson et al. (2003) investigated vertical posture and head stability in patients with chronic neck pain. This research was constituted of 3 groups, an asymptomatic (control) \((n = 16)\), NSNP \((n = 9)\) and WAD \((n = 9)\) with a mean age of \(41.7 \pm 9.3\). Jørgensen et al. (2011) investigated neck pain and postural balance among workers with high postural demands in a cross-sectional study. This research constituted of 2 groups, an asymptomatic (control) \((n = 109)\) and an NSNP \((n = 85)\), with a mean age of \(45.7 \pm 8.4\) (age range 23 to 69). Two conflicting factors were identified when reviewing Jørgensen et al. (2011) research. During the postural control protocol participants stood with the arms crossed over the chests during data acquisition, and the CoP data were reported as the 95% confidence ellipse area.

Juul-Kristensen et al. (2013) investigated increased neck muscle activity and impaired balance among females with whiplash-related chronic neck pain in a cross-sectional study. This research was constituted of 2 female groups, an asymptomatic (control) \((n = 10)\) and a WAD \((n = 10)\), with a mean aged of 36.8 (age range 21 to 58). Three conflicting factors were identified when reviewing Juul-Kristensen et al. (2013) research. de Zoete et al. (2017) misrepresented WAD as NSNP, the sample only consisted of females and the CoP data were reported as the 95% confidence ellipse area.
Table 8.3. Several Articles Constituting Non-specific Neck Pain Pooled Sway Area Data.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes Closed</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Foot Positioning</td>
<td>Narrow Stance</td>
<td>Narrow Stance</td>
<td>Narrow Stance</td>
</tr>
<tr>
<td>Firm Surface</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sample Duration</td>
<td>30 Seconds</td>
<td>30 Seconds</td>
<td>30 Seconds</td>
</tr>
<tr>
<td>Trials</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Reported Parameter</td>
<td>Sway Area</td>
<td>95% CEA</td>
<td>95% CEA</td>
</tr>
<tr>
<td>Asymptomatic (mm²)</td>
<td>1090 (650)</td>
<td>699 (386)</td>
<td>653 (286)</td>
</tr>
<tr>
<td>NSNP (mm²)</td>
<td>1660 (650)</td>
<td>884 (587)</td>
<td>N/A</td>
</tr>
<tr>
<td>WAD (mm²)</td>
<td>N/A</td>
<td>N/A</td>
<td>1186 (609)</td>
</tr>
</tbody>
</table>

95% CEA = 95% Confidence Ellipse Area, NSNP = Non-Specific Neck Pain, WAD = Whiplash Associated Disorder, M = Mean, SD = Standard Deviation, N/A = Not Applicable.

After reviewing three research projects that constituted the de Zoete et al. (2017) pooled sway area data, it was revealed that several inconsistencies existed between these research projects. There was no consistency when comparing the mean age across all three studies, and in relation to this research project, age comparably was non-existent. One sample consisted of females only, two studies reported the sway area as the 95% confidence ellipse area which is generated differently to either the CoP sway area or this research project’s 95% CC. One study used an unnatural stance position, requiring the participants to cross their arms on their chest. One worrying inconsistency involved de Zoete et al. (2017) misrepresenting WAD data as NSNP data. It is very well accepted that WAD CoP data demonstrate greater mean CoP parameters than those observed in NSNP participants (Ruhe et al., 2011; Silva & Cruz, 2013).
While many dissimilar factors were identified among the studies that constituted the pooled sway area data (Table 8.3), many dissimilar factors were also identified between these three studies and this research project. One postural control protocol that has the potential to account for the differences observed between the de Zoete et al. (2017) pooled sway area data and this research project’s data are the samples duration. Carpenter, Frank, Winter, and Peysar (2001) investigated the affect trials consisting of 15, 30, 90 and 120 seconds had on CoP parameters, and identified a progressive increase in the parameter’s magnitude as the samples’ duration increased. The specific CoP parameter that exhibited the greatest significant increase was the A/P root mean square values (Figure 8.3). Carpenter et al. (2001) determined that a positive correlation existed between reliability and sample durations. A longer duration increased reliability, and possibly improves the likelihood of identifying more subtle differences between groups.

![Figure 8.3](image)

*Figure 8.3.* Mean root mean square values and standard error bars for different sample durations from 15 to 120 seconds. Anterior/Posterior root mean square (solid line) and Medial/Lateral root mean square (dashed line), adapted from (Carpenter et al., 2001).
Doyle, Hsiao-Wecksler, Ragan, and Rosengren (2007) investigated sample durations of 30, 60, and 90 seconds with all CoP parameters derived from 30 second increments of the single 90 second trial. Acceptable levels of reliability ($r > 0.7$) were not achieved for the commonly used CoP parameters until the samples’ duration were $\geq 60$ seconds. Doyle et al. (2007) suggested that to reach acceptable levels of reliability, trial durations should be no less than 60 seconds and consist of no fewer than 5 trials. The sample duration chosen for this research project reflected the best practice recommendation of 90 seconds by Ruhe et al. (2010). The findings of Carpenter et al. (2001) related to sample duration indicate that CoP parameters would be of a larger magnitude during a 90 second trial when compared to a trial lasting 30 seconds. The larger CoP parameter values observed between the de Zoete et al. (2017) pooled sway area data and this research project’s 95% CC data could be explained by the larger sample duration, and the numerous inconsistent factors identified between the two studies.

Table 8.4.  
Comparability Between Pooled Sway Area Data and This Research Project’s 95% Confidence Circle Data for Asymptomatic Participants.

<table>
<thead>
<tr>
<th>PC Variable</th>
<th>de Zoete et al. (2017) Asymptomatic Participants ($n = 298$)</th>
<th>Research Project Asymptomatic Participants ($n = 150$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm Surface Eyes Closed</td>
<td>Lower Limit</td>
<td>Upper Limit</td>
</tr>
<tr>
<td></td>
<td>274mm²</td>
<td>1090mm²</td>
</tr>
<tr>
<td>Mean ($SD$)</td>
<td>Sway Area 653mm²</td>
<td>1369mm² (711)</td>
</tr>
<tr>
<td>$\pm 1 SD$</td>
<td>N/A</td>
<td>658mm² / 2080mm²</td>
</tr>
</tbody>
</table>

PC = Postural Control, SD = Standard Deviation, N/A = Not Applicable, $n$ = Number of Participants.
Compliant surface CoP parameters were not reported in the previous three studies (Table 8.3), therefore this research project’s CS findings are not discussed here. However, this research project’s FS CoP 95% CC data was compared to the de Zoete et al. (2017) pooled sway area data, as reported by both studies. Referring to this research project, the mean area was 716mm$^2$ larger, the maximum area was approximately 4 times larger, and the mean area was 279mm$^2$ larger than de Zoete et al.’s (2017) upper limit (Table 8.4). The evidence related to the numerous inconsistencies identified between this research project and the review by de Zoete et al. (2017) makes accurate comparability tenuous.

Table 8.5. 
*Comparability Between Pooled Sway Area Data and This Research Project’s 95% Confidence Circle Data for Non-specific Neck Pain and Asymptomatic Non-Lordotic Participants.*

<table>
<thead>
<tr>
<th>PC Variable</th>
<th>de Zoete et al. (2017)</th>
<th>Research Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm Surface</td>
<td>Non-specific Neck Pain ($n = 285$)</td>
<td>Asymptomatic Non-lordotic ($n = 150$)</td>
</tr>
<tr>
<td>Eyes Closed</td>
<td>Lower Limit</td>
<td>Upper Limit</td>
</tr>
<tr>
<td></td>
<td>251mm$^2$</td>
<td>1660mm$^2$</td>
</tr>
<tr>
<td>Mean ($SD$)</td>
<td>884mm$^2$</td>
<td>N/A</td>
</tr>
<tr>
<td>± 1 SD</td>
<td>N/A</td>
<td>705mm$^2$ / 2119mm$^2$</td>
</tr>
</tbody>
</table>

PC = Postural Control, SD = Standard Deviation, N/A = Not Applicable, $n$ = Number of Participants.

The first of the two secondary research questions enquired: is the level of postural control within an asymptomatic cervical non-lordotic sample similar to those established in NSNP samples during comparable testing protocols? It is apparent that comparability between this research project’s asymptomatic non-lordotic participants and NSNP participants in the de Zoete et al. (2017) study is not practical presently. However, this research project’s FS asymptomatic non-lordotic CoP 95% CC data were compared to the de Zoete et al. (2017) NSNP pooled sway area data, as reported by this research project and de
Zoete et al. (2017) research without modification. Referring to this research project, the mean area was 528mm$^2$ larger, the maximum area was approximately 2.5 times larger, and the mean area of 1412mm$^2$ was below the de Zoete et al. (2017) upper limit of 1660mm$^2$ (Table 8.5). Surprisingly, comparing the NSNP and asymptomatic non-lordotic participants CoP data, it appears these two datasets are more closely aligned than the CoP data for asymptomatic participants.

However, this finding would not be considered sound in respect to acting as a function biomarker due to the numerous inconsistent methodological factors identified. Comparing asymptomatic non-lordotic participants’ CoP data with similar data acquired from NSNP participants to possibly clinically identify a transition into early cervical pathology is not achievable with the evidence available currently. It is, however, clear that future applications and research directions concerning the topics broached during this discussion show merit. The use of CoP parameters to discriminate variability in postural control functionality, either intra-individually or inter-individually, is not a new concept. To identify differences within an asymptomatic sample, in contrast to an asymptomatic (control) sample, being compared to a pathological sample, it will require strict standardisation of several factors including terminology, the metrological characteristics of the instruments used to acquire the data, postural control protocols, statistical analysis and reporting of CoP parameters; to improve, data comparability, test re-test reliability and overall validity.
A concerted effort must be undertaken by future researchers to commence postural control research that has the desire effect of reporting new research findings but also reporting findings that are comparable and transparent. To commence and publish research projects with these two aims in mind will generate literature that will assist in reducing the problems of inconsistent factors identified during this discussion. The discussion involving future applications and research directions is vital to stimulate concepts that can improve the quality and depth of our understanding within a domain when concepts are modelled and implemented successfully. The functional drive of the scientific method is to scrutinise events in a scientific way by devising a hypothesis then obtaining the relevant evidence to either prove or disprove such hypothesis.

8.6 Successful Application of Postural Control as a Functional Biomarker

In alternative areas within the overarching postural control domain, have CoP parameter analyses been used successfully to assist in formulating biomarkers with the ability to clinically identify early pathology? Typically, in the domain of postural control, research is conducted between an asymptomatic (control) sample and a similar age-matched pathological sample. This is analogous to an asymptomatic (control) sample being compared to a WAD sample within the postural control domain investigating cervical concerns. It is abundantly clear that pathological and/or WAD participants exhibit greatly diminished CoP parameters when compared against asymptomatic (control, physiological) parameters.
Mancini et al. (2012) investigated longitudinally whether CoP parameters were able to be used as a biomarker for the early detection of progression in Parkinson’s disease, to potentially improve patient care outcomes. Mancini et al. (2012) determined that objective CoP parameters, particularly the medial/lateral range deteriorated over a one-year period despite only a slight reduction in the unified Parkinson's disease rating scale scores over the same period. This finding suggested that CoP parameters’ sensitivities are sufficiently accurate to measure the progression of Parkinson’s disease prior to the onset of treatment.

Horak and Mancini (2013) investigated the accuracy of body-worn sensors to act as objective biomarkers of balance in Parkinson’s disease. It was determined that body-worn sensors provided objective CoP measures. However, Horak and Mancini (2013) suggest that despite this objective finding, a major gap in developing balance biomarkers is the lack of objective comparative CoP measures related specifically to Parkinson’s disease pathology. Despite this gap, Horak and Mancini (2013) advocate strongly for the use of CoP parameters as biomarkers, as these measures are objective potent indicators of biological process with the potential capacity to assist in the diagnosis of pre-symptomatic and symptomatic diseases. T.-Z. Chen et al. (2014) suggest that there is compelling evidence that decreased postural control parameters are recordable at very early clinical stages of Parkinson's disease.
The findings of T.-Z. Chen et al. (2014) determined that patients with disorders demonstrate subtle decreased objective CoP parameters, and these parameters could potentially be used as biomarkers capable of detecting early Parkinson's disease in the period between the appearance of initial symptoms and the full development Parkinson's symptomatology. Rovini, Maremmani, and Cavallo (2017) recently published a systematic review into the capacity of wearable sensors to support Parkinson’s disease diagnosis and treatment. Rovini et al. (2017) reported that regardless of the technology used to detect CoP parameters, these measures assist Parkinson’s disease diagnosis. Firstly, CoP parameters provide postural control information not accurately recognised by conventional testing modalities, and objective CoP parameters can distinguish mild from moderate disease stages. Importantly, objective CoP parameters are well situated to predict future problems related to Parkinson’s disease.

The Rovini et al. (2017) review proposed CoP parameters be employed as an unbiased and automated measure that can be compared to measures obtained by the clinician. This review acknowledges the value CoP parameters exhibit across the Parkinson’s disease diagnostic spectrum, indicating the methodologies associated with these parameters’ usage are developing. Ferrazzoli et al. (2015) tested Parkinsonian patients not displaying outward, subjective signs of decreased balance control. Testing determined that objectively decreased CoP parameters were recorded when compared to the controls. Ferrazzoli et al. (2015) determined that decreased CoP parameters in Parkinsonian patients are identifiable before the outward appearance of movement disorders develop. In addition, CoP parameters have the capacity to be used as a biomarker to enhance proactive treatment protocols that may prevent or delay the onset of Parkinson’s disease.
It is clear within the postural control domain relating to Parkinson’s disease research, that the area concerning the use of CoP parameters functioning as viable biomarkers has been explored. There are encouraging research results that support the application of decreased postural control CoP parameters as functional biomarkers with the capacity to identify early stages of Parkinson’s disease. The biological mechanisms associated with NSNP and the pathological predisposition of the non-lordotic state need to be considered. NSNP sufferers display decreased postural control (Ruhe et al., 2011; Silva & Cruz, 2013), and the non-lordotic state promotes degeneration and pain syndromes (Ames et al., 2013; Iyer et al., 2016; Nouri et al., 2015). The ability to use non-lordotic subtypes as a prognostic tool represents an exploitable gap in our understanding. Given the positive results published within the domain of Parkinson’s disease. It is possible that future researchers could expand on the current findings of this research project and develop a comparable understanding related to cervical non-lordotic CoP parameters and their use as a prognostic biomarker to identify potential NSNP sufferers. Accordingly, objectively determined decreases in CoP parameters may have the capacity to identify the subtle transitional state within the nervous system that results in individuals developing NSNP.
8.7 Potential Mechanisms Responsible for Maladaptive Decreased Postural Control: Responding to the Third, Secondary Research Question

- If asymptomatic participants, exhibiting conformational cervical subtypes other than the natural cervical lordotic subtype, show evidence of maladaptive decreased postural control, how does the literature clarify a potential positive finding?

Healthy sensorimotor integration is considered noisy, and transpires with a latency. Fundamentally, accurate afferent sensory input must be interpreted and then integrated effectively to generate an appropriate situation-specific motor program. Healthy sensorimotor integration is dependent on flawless identification of sensory stimuli, then precise conduction through the peripheral nervous system. Communication of sensory stimuli within the CNS necessitates impeccably coordinated synaptic transmission within several key integration areas to facilitate the most appropriate motor response to counter the sensory stimuli (Shadmehr et al., 2010).

Healthy sensorimotor integration is fluid, with the capacity to instantaneously adapt to changes from either the internal or the external environment. The objective of integration within the CNS is appropriate motor control strategies. To achieve this end goal, the brain estimates the afferent sensory input it ought to perceive from the current motor strategy. As the subsequent afferent input arrives in the brain, it is paralleled and contrasted with the estimated afferent input to form an overall representation of the environment. This contrasting of both actual and estimated afferent input allows the brain to deliver feedback on the current motor response. Feedback achieves fast trajectory corrections to the current motor program which allows adaptations within a changing environment to be overcome successfully (Shadmehr et al., 2010).
Healthy balance parameters require the precise quantity and quality of sensory information to be perceived by key structures within the proprioceptive, visual and vestibular systems, and then input accurately into the CNSs integration areas (Abrahamova & Hlavacka, 2008; Peterka & Black, 1989; Quek et al., 2018). Postural sway describes the fluctuating variability of the body’s CoM while maintaining balance. Postural control is exceedingly complex, requiring precise integration between peripheral and central neuromuscular systems. Postural control is intrinsically noisy, and fortunately this inherent noise has enabled researchers to observe the degree of variability related to a specific stance task. It has been postulated that low levels of variability reflect optimum neuromotor control, while higher levels are maladaptive and not advantageous to the human sensory motor system (Konig et al., 2016; Ludwig, 2017; Paillard & Noe, 2015; Palmieri et al., 2002).

Fevered debates continue to focus on the precise causative mechanism responsible for the higher levels of CoP variability observed within all age groups. Sensorimotor control is becoming an increasingly reported outcome in neck pain research (Quek et al., 2018; Strimpakos, 2011) with suggestions that this decreased postural control witnessed within the neck pain population is the consequence of changes to the inherent motor control strategies used to remain upright (Woodhouse & Vasseljen, 2008). Uncertainty exists as to the exact pathophysiological mechanisms underlying non-traumatic neck pain, "non-specific" is a commonly used prefix to clinically describe this neck pain (Hush, Maher, & Refshauge, 2006). In mechanical terms, structures of the neck such as muscles, ligaments, zygapophyseal joint capsules, intervertebral discs, nerve roots and dura are all innervated structures capable of providing nociceptive stimulus (Bogduk, 1988). However, pain is a personal emotion with the potential to be stimulated through several predictive factors such as sociodemographic status, leisure activities, psychosomatic stress, fatigue, sleep difficulties (Siivola et al., 2004),
C. J. Woolf (2010) broadly classified pain into three classes: nociceptive pain is inherently protective in nature, detecting noxious stimuli that have the potential of damaging tissue; overt tissue damage is associated with inflammatory pain which results in pain hypersensitivity to prevent excessive movement and avoidance behaviours during the healing process; and disease of the neural tissue results in pathological pain whereby damaged neural tissue causes neuropathic pain and abnormal neural processing results in dysfunctional pain. Both sources of pathological pain result in maladaptive low threshold pain (Figure 8.4). Currently, the most supported theoretical framework attempting to detail the primary pathophysiological mechanisms responsible for decreased postural control is pain-induced, aberrant cervical afferent proprioceptive input. Upon reaching the postural control integration areas, the aberrant afferent input fails to be coordinated effectively. Maladaptive inter-neuronal synaptic transmission formulates inappropriate motor control strategies unable to successfully adapt to changing situations within internal and external environments (Ruhe et al., 2011; Treleaven, 2008; Woodhouse & Vasseljen, 2008).
Haavik-Taylor and Murphy (2007) suggest there is excellent evidence supporting this postulated mechanism; however, the full developmental picture is yet to be elucidated. Ruhe et al. (2011) supported this view and added there is conjecture in the literature as to whether proprioceptive or nociceptive afferent input is the primary causative mechanism that results in abnormal integration leading to decreased postural control. Overwhelming evidence indicates as asymptomatic participants age, deterioration within the integration areas results in decreased postural control and increased postural sway (Ekdahl et al., 1989; Forth, Metter, & Paloski, 2007; Woollacott & Shumway-Cook, 1990). Decreased postural control is also apparent in NSNP and WAD participants when compared with asymptomatic (control) participants (Field et al., 2008; Ruhe et al., 2011; Silva & Cruz, 2013).

Accurate afferent neural information from cervical muscle spindles and cervical joint receptors is essential for central integration during stance (Darnell, 1983; Mancini & Horak, 2010; Ruhe et al., 2011; Silva & Cruz, 2013; Winkelstein, Nightingale, Richardson, & Myers, 2000). Muscle spindles are highly specialised, discrete, stretch receptors within the muscle and are orientated parallel to the vastly larger muscle fibres. Muscle spindles primarily detect changes in the length of the muscle. Their afferent input conveys information regarding the muscle’s length to the integration areas. The muscle spindle has both sensory and motor fibres (gamma), the motor fibres allowing the spindle to contract as the muscle shortens thus maintaining muscle spindle sensitivity, regardless of the muscle’s contracted length (Tortora & Derrickson, 2008).
Figure 8.4. Three divisions of pain classification. A. Nociceptive pain, detects noxious stimuli and is protective. B. Inflammatory pain, tissue damage causing pain hypersensitivity until healing occurs. C. Pathological pain, disease state, damaged neural tissue (neuropathic pain) or abnormal function (dysfunctional pain), adapted from (C. J. Woolf, 2010).
Moseley and Hodges (2005) postulated that acute pain may inhibit and interfere with spinal motor-pathways and cortical motor processing, which generates detrimental alternate postural adjustment strategies which are perceived objectively and subjectively as decreased postural control. The Stanton et al. (2016) systematic review supported this view and suggested the relationship between chronic NSNP and muscle spindle activity is neurologically complex when evaluating the integration response that culminates in position sense awareness. Stanton et al. (2016) were concerned that the lack of neural tissue trauma would seem to indicate that the peripheral mechanoreceptors are not affected, and the subsequent proprioceptive dysfunction observed in NSNP participants may be perpetuated by spinal cord or higher level maladaptive integration. Muscle pain induced experimentally has been shown to alter the central modulation capacity of muscle spindle afferents (Capra & Ro, 2000), while inducing muscular neck pain stimulated decreased postural control in young healthy adults (Vuillerme & Pinsault, 2009). Induced muscular pain has been also been reported to inhibit motor neuron excitability at both cortical and spinal cord levels (Le Pera et al., 2001). Noninduced NSNP has been reported to reduce cervical ROM, peak velocity, smoothness of movement, and repositioning acuity (Sjölander, Michaelson, Jaric, & Djupsjöbacka, 2008).

Thunberg et al. (2001) experimentally demonstrated that reflex connections exist between cervical joint nociceptors and the gamma motor neurons that innervate the muscle spindles in cats’ dorsal neck muscles. Inflammatory mediated stimulation of gamma motor neurons resulted in muscle spindle facilitated muscular stiffness. Thunberg et al. (2001) postulated that neck pain could induce a pathophysiological long lasting positive feedback activation of the gamma motor neurons, leading to increased muscular stiffness. Several researchers postulate that maladaptive gamma motor neuron activity has the capacity to
diminish the functionality of the muscle spindle, leading to detrimental sensorimotor integration and decreased postural control as the body’s CoM in ineffectively regulated of the body’s BoS (Casadio, Morasso, & Sanguineti, 2005; Ruhe et al., 2011; Thunberg et al., 2001).

Suboccipital and deep neck muscles are densely populated with the largest quantity of muscle spindles per gram of muscle mass, compared to any other specific muscle or muscle group within the muscular system (Liu et al., 2003; Peck, Buxton, & Nitz, 1984). Extremely high muscle spindle density permits precise neck movement coordination while functioning as vital receptors that supply afferent input used during central integration of stance and head positioning (Liu et al., 2003; Quek et al., 2018). It has been postulated that postural asymmetries diminish the accuracy of the afferent neural information from muscle spindles and cervical joint receptors, an essential requirement for central integration during postural control (Darnell, 1983; Mancini & Horak, 2010; Ruhe et al., 2011; Silva & Cruz, 2013; Winkelstein et al., 2000). A naturally lordotic alignment is considered optimal for the cervical spine when considering functionality and health-related quality of life factors (Abelin-Genevois et al., 2014; Ames et al., 2013; Nouri et al., 2015). Several researchers have suggested that a reduction in the cervical lordosis tends to increase the participant’s susceptibility to NSNP (D. D. Harrison et al., 2004; McAviney et al., 2005; Silva et al., 2009a; Yip et al., 2008).
A ten-year longitudinal study indicated 76 previously asymptomatic participants from a cohort of 223 developed NSNP, and participants with altered sagittal cervical alignment demonstrated advanced levels of osseous degeneration and were more inclined to report NSNP (E. Okada et al., 2009). Miyazaki, Hymanson, and Morishita (2008) investigated sagittal cervical alignment and its relationship to IVD degeneration in NSNP participants. Miyazaki et al. (2008) indicated participants exhibiting non-lordotic subtypes exhibited an apparent decrease in cervical translational and angular motion across all segmental levels when compared to participants with a lordotic subtype. Furthermore, indicating non-lordotic subtypes places greater stress on the cervical spine and potentially contributes to the pathogenesis of IVD degeneration.

McAviney et al. (2005) agreed that non-lordotic subtypes stress the anterior margin of the vertebral body and intervertebral disc, and potentially act in the pathogenesis of the three-joint complex. Szeto et al. (2005) identified participants with FHP exhibited a predisposition for NSNP and altered motor control within their cervical musculature while seated. Szeto et al. (2005) postulated the observed neurological changes represent a detrimental plastic change within the CNSs integrations areas. Greig, Straker, and Briggs (2005) were able to identify atypical cervical erector spinae and upper trapezius hyperactivity in asymptomatic paediatric participants using a variety of head positions while interfacing with different information technologies while seated. Lau, Chiu, and Lam (2010) indicated that as the degree of FHP increased, as identified by anterior head translation, a positive correlation was shown between the level of neck disability and the level of pain intensity.
A significant epidemiological contributor to asymptomatic neuromusculoskeletal adaptations is the simple act of sitting; FHP is either acquired or accentuated while seated (D. D. Harrison, Harrison, Croft, Harrison, & Troyanovich, 1999). Non-lordotic subtype causation lean towards a slowly adapting asymptomatic alteration in the cervical alignment pattern is brought about by significant time spent adopting a flexed craniovertebral posture such as those involved in screen-based activities. This detrimental alignment alteration can either develop from a previously existing cervical lordosis or develop independently as a non-lordotic cervical spine; the latter appears to have greater support within the literature relating to a younger population (Brink & Louw, 2013; Fares et al., 2017; Takeshima et al., 2002; Yukawa et al., 2012). Non-lordotic subtypes may initially be functional, and following many hours of static loading, a habitual fixed non-lordotic structural posture gradually develops. As biomechanical loading parameters change, so too do the sensorimotor integration strategies required to maintain these atypical statically adopted postures, consequently maladaptive uncoordinated centrally integrated movement patterns develop (Szeto et al., 2005).

Evidence points towards these uncoordinated movement patterns developing gradually while the quality and quantity of afferent spindle information in adversely modified (Roijezon et al., 2015). Altered afferent spindle inputs have been advocated in the causal relationship of decreased postural control and muscular coordination (Konig et al., 2016; Ruhe et al., 2011; Treleaven, 2011), increased cervical spine repositioning error (Yong et al., 2016) and repeated structural microtrauma (Falla & Farina, 2007). Ruhe et al. (2011) postulated long term neurophysiological changes may primarily be involved in the initial transition period leading up to the point decreased postural sway is objectively apparent. Non-lordotic subtypes modify cervical spine muscle-tendon lengths extensively when compared to the natural lordotic subtype. Modification takes the form of either lengthening or
shortening, depending on the location of the muscle’s attachment points and the orientation relationship the muscle has with the osseous structures of the craniovertebral region (Khayatzadeh et al., 2017).

Adopting a sagittal vertical alignment of 26 mm dramatically shortens the suboccipital muscles with the RCPma and RCPmi muscles length decreased by 20% and 15%, respectively. This sagittal vertical alignment lengthens the deep (C6/7 to C4) and superficial (T1 to C4) multifidus by 9.4% and 13%, respectively (Figure 8.5). Non-lordotic subtypes that increase the cervical spines sagittal vertical alignment increase atlanto-occipital extension in conjunction with the upper cervical vertebrae, while flexing the lower cervical vertebrae (Khayatzadeh et al., 2017). Furthermore, sustained and atypical muscular contractions occur, as this posture is statically maintained which further exacerbates the adopted craniovertebral postural deformity (J. H. Lee, 2016).

Regardless of the non-lordotic subtype, cervical muscles either shorten or lengthen beyond their normal resting length to accommodate the adopted craniovertebral alignment pattern. It is plausible that given an appropriate timeframe, the previous functional resting length of these muscles will accommodate to the non-lordotic subtype and become the new “normal” dysfunctional resting length (Neumann, 2013). As mentioned, sub-occipital muscles have the largest muscle spindle density in the body whereas the equally high spindle density within the cervical spines rotators and multifidi afford these muscle groups the explicit ability to act as “pure sense organs” for precise kinematic monitoring of the craniovertebral region (Peck et al., 1984). This portrays the upper cervical spine’s significance in supplying the precise quality and quantity of proprioceptive information required to effectively modulate sensorimotor integration during stance (de Zoete et al., 2017; Liu et al., 2003; Roijezon et al., 2015; Silva & Cruz, 2013)
Figure 8.5. The percent change in muscle lengths with anteriorly increased sagittal vertical alignment (SVA). A. Head offset, SVA = 0 mm. B. Forward head posture, SVA = 26 mm. C. Severe forward head posture SVA = 40 mm, adapted from (Khayatzadeh et al., 2017).

Haavik-Taylor and Murphy (2007) postulated that painless aberrant spinal kinematics can develop in the general population without any self-awareness related to subjective symptomatology. Shakespeare et al. (1985) demonstrated structurally atypical osseous kinematics produced reflex inhibition of the joints’ associated muscles which ultimately produced disparities in the muscle’s afferent input. This finding was achieved with little or no pain over a two-week period, suggesting that over time altered proprioception has the potential to induce maladaptive changes within the CNS. Gradually, aberrant joint kinematics can permanently alter the way the CNS integrates and responds to sensory information (Haavik-Taylor & Murphy, 2007).
Haavik-Taylor and Murphy (2007) postulate that painless aberrant joint kinematics perpetuate maladaptive integration that inevitably thwarts protective MSK reflexes from adequately guarding joint structures, predisposing them to repeated structural microtrauma. The resultant tissue damage generated from repeated structural microtrauma initiates inflammatory pain which augments the entire aberrant sensorimotor integration process. Over time, continued structural microtrauma generates further pain culminating in further maladaptive plastic changes in the integration areas of the CNS; additional time and trauma may be responsible for turning this issue from an acute episode to a chronic situation.

Pathophysiologial markers have manifested themselves when symptoms are present, and the literature has focused considerable attention on attempting to understand the causative neurological mechanism responsible for decrease postural control in this symptomatic population. However, an absence of MSK pain does not mean MSK health. This research project contributed significantly to our collective understanding related to the maladaptive asymptomatic (non-lordotic) phase associated with postural control variability. Although causation is speculative, the identified evidence suggests that the findings of this research project may constitute the objective evidence required to further investigate the preceding asymptomatic stages of NSNP. An evidence-based bridge between the decreased postural control observed in non-lordotic asymptomatic participants and that of NSNP symptomatic participants is both required and achievable. This link may take the form of an early structurally induced, maladaptive sensorimotor control strategy that manifests over an extended period while flourishing in the complete absence of subjective pain awareness (Figure 8.6).
Maladaptive sensorimotor control strategies resulting from altered kinematics generated through morphological spinal adaptation, adapted from (Falla & Farina, 2007; Neumann, 2013; Szeto et al., 2005; Treleaven, 2008), illustration by Lee Daffin.
8.8 Conclusion

In conclusion, the significant CoP findings exhibited by this research project were achieved without a nociceptive contributor. Eliminating pain as causation, when explaining the decreased postural control observed within the non-lordotic participants, compels causation to be sort from within the proprioceptive domain. Substantiated findings indicate pain is detrimental to accurate proprioceptive input. Pain significantly alters afferent muscle spindle receptors, producing aberrant afferent input consequently. In nonhuman studies, gamma motor neurons react to induced inflammatory mediated pain by facilitated muscular stiffness which is postulated to eventually cause detrimental sensorimotor integration and decreased postural control. Pain has been positively correlated with decreased postural control in NSNP and WAD participants. It is clear pain adversely alters sensorimotor integration and decreases postural control as a result.

Attempting to unravel and develop a cohesive evidence-based understanding concerning the maladaptive asymptomatic (non-lordotic) phase is difficult given this incredibly complex and multifactorial domain. It is evident that non-lordotic subtypes biomechanically stress the cervical spine, and, as such, generate a greater predisposition to NSNP. It is evident that cervical non-lordotic subtypes retain structurally unsound biomechanical motion; aberrant joint kinematic motion can subsist in a painless state and possibly stimulate atypical muscle spindles afferent input. Through the passage of time, aberrant afferent input becomes permanently entrenched within the sensorimotor integration process. Once entrenched, this perpetuates maladaptive integration that thwarts protective MSK reflexes, predisposing articular structures to repeated microtrauma. Continued microtrauma generates pain culminating in further maladaptive plastic changes in the integration areas of the CNS.
Scarcity is apparent within the relevant literature concerning structured discussions involving the NSNP sufferer's pre-symptomatic phase; theoretically, all NSNP sufferers were asymptomatic at some stage. Therefore, it is feasible that objective indications are present, and could identify the possibility of transition into the NSNP phase. Postural control is perfectly situated to identifying this transitional stage. The objective findings established during this research project have the potential to stimulate discussions and direct future research endeavours within the developing postural control domain investigating asymptomatic decreased postural control.

The evidence introduced while answering this research question is sufficiently plausible to support a causative mechanism that represent the maladaptive asymptomatic (non-lordotic) phase. This phase is responsible for establishing significantly decreased postural control parameters when compared to asymptomatic lordotic subtypes.
References


Appendices
The efficacy of sagittal cervical spine subtyping: Investigating radiological classification methods within 150 asymptomatic participants

ABSTRACT
Aims: The aim of this study is to (1) compare and contrast cervical subtype classification methods within an asymptomatic population, and (2) identify inter-methodological consistencies and describe examples of inconsistencies that have the potential to affect subtype classification and clinical decision-making.

Methods: A total of 150 asymptomatic 18–30-year-old participants met the strict inclusion criteria. An erect neutral lateral radiograph was obtained using standard procedures. The Centroid, modified Takahama/Herdman methods and the relative rotation angle in cases of nonagreement were used to determine subtype classifications. Cohen’s kappa coefficient (κ) was used to assess the level of agreement between the two methods.

Results: Nondiagnostic classifications represented 66% of the cohort. Subtype classification identified the cohort as, lordosis (51), straight (37), global kyphosis (30), sigmoidal (13), and reverse sigmoidal (RS) (19). Cohen’s kappa coefficient indicated that there was only a moderate level of agreement between methods (κ = 0.531). Methodological agreement tended to be higher within the lordotic and global kyphotic subtypes whereas, straight, sigmoidal, and RS subtypes demonstrated less agreement.

Conclusion: This is the first study of its type to compare and contrast cervical classification methods. Subtypes displaying predominantly extended or flexed segments demonstrated higher levels of agreement. Our findings highlight the need for establishing a standardized multi-method approach to classify sagittal cervical subtypes.

Keywords: Asymptomatic, cervical classification, kyphosis, lordosis, sigmoidal

INTRODUCTION
The cervical spine is naturally lordotic,[1,2] contributing to the spine’s overall sagittal balance in association with the interconnected alignment variabilities within the thoracolumbar spine, pelvis, and lower limbs.[3,4] A distinction must be made between methods that are used to classify cervical alignment subtypes and methods that produce angular measurements. The Centroid,[5,6] Kamata’s line drawing,7,8 Takahama et al.[9] and Herbst[10] methods are commonly used to classify cervical subtypes. The Cobb, Posterior Tangent (relative rotation angle [RRA]),9,10 Cervical Centroid Lordosis and Ishihara methods9 all produce angular measurements that quantify the curve, but not its specific subtype.

Descriptors of the various cervical alignment subtypes has improved considerably. Ruanchaininikom et al.[11] introduced the term global kyphosis to describe both a global flexed segmental arrangement and also the concept of focal kyphotic sections within the lower or upper cervical spine of sigmoidal-types. Harrison et al.[12] described various subtypes

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within the cervical spine. These subtypes are typically classified as lordotic (L-type), straight (St-type), global kyphotic (Gk-type), sigmoidal (S-type), and reverse sigmoidal (RS-type). Cervical subtype classification involves identifying and using numerous radiological landmarks to develop an overall impression of the cervical spine’s sagittal alignment. A variety of visual and numerical methods have been developed and modified over time to fulfill this requirement.\(^{5,8,10}\)

The Centroid method\(^{4,6}\) involves visually determining the location and numerical distance of centrally located points within the vertebral bodies of C3–C6 to a central line connecting C2 and C7. The Takekita method\(^{49}\) involves visually identifying the inherent sequential alignment of the posterior vertebral body margins (PVBM) from C2 to C7. The generated PVBM conformational shape (CSH) is classified according to its relative subtype. Conversely, the Herbst method\(^{19}\) requires visual interpretation of the convergence or divergence posteriorly of five lines that equally transect the intervertebral discs between C2 and C7. At present, no single “gold standard” methodology exists to classify sagittal cervical alignment subtypes. However, these are the most accepted methods within the literature.

Considerable advances have been made regarding the various nonlordotic subtypes and their contribution to the pathogenesis of degenerative cervical myelopathy (DCM), and the significant impact that this has on the quality of life of the elderly.\(^{12,6,16-18}\) Two recent reports have independently determined that approximately one-third of asymptomatic participants displayed nonlordotic subtypes.\(^{19,20}\) The mounting evidence that nonlordotic subtypes are increasing within apparently healthy populations is concerning considering the detrimental effects of DCM.\(^{2,4,12,22}\) As DCM is the leading cause of spinal cord dysfunction worldwide,\(^{16}\) an increase in nonlordotic subtypes could indicate a potential future rise in DCM symptomatology in the general population.

Cervical subtyping is essential within research and clinical environments\(^{5,7,8,12}\) to establish baseline and postintervention alignment classifications. Pre- and post-operative decision making relies on an accurate understanding of the various cervical alignment subtypes, as sagittal alignment influences operative outcomes.\(^{17,12,22,24}\) Scheer et al.\(^{12}\) suggested the necessity for a comprehensive approach to assess global cervical-pectoral relationships. Therefore, a precise understanding of the limitations within cervical subtyping methodologies is critical to achieve this future direction.

Accordingly, the purpose of this research is to (1) compare and contrast cervical subtype classification methods within an asymptomatic population, and (2) identify inter-methodological agreement and describe areas of disagreement that have the potential to affect subtype classification and clinical decision-making. It is hoped that this will stimulate further research and discussion that leads to the development of a standardized sagittal subtyping classification method.

**METHODS**

The sample population consisted of 61 male and 89 female participants [Table 1]. The tools that were used to assess participant eligibility were a self-reporting questionnaire (SRQ),\(^{39-41}\) 36-item short-form health survey (SF-36),\(^{20}\) neck disability index (NDI),\(^{21}\) and a physical examination.\(^{32,33}\) The SRQ was formulated from published criteria to exclude participants that could negatively influence asymptomatic measures. All included participants demonstrated an asymptomatic SRQ, with all health and neuromusculoskeletal SF-36 scores above the National Health Survey SF-36 population norms.\(^{26}\) In addition, the NDI upper limit inclusion score was 12, where a score >15 was likely to indicate neck pathology.\(^{25}\) The physical examination excluded participants that demonstrated positive neurological and/or orthopaedic findings.

Approval was obtained from the Institutional Research Ethics Committee (514/607), with written informed consent obtained from all eligible volunteers in accordance with the institutional human research ethics requirements. The current study is one component of a larger project investigating the influence of cervical alignment on postural sway. This accounts for the radiographic procedures on asymptomatic subjects.

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**Radiographic procedures, instruments, and measurements**

A single lateral radiograph was taken with a tube-to-wall mounted Bucky distance of 1.5 m. The central ray was aligned approximately at the level of C4. Each participant was positioned with their right shoulder touching the Bucky and instructed to adopt a relaxed neutral erect stance position with their head looking toward the horizon. The participant’s shoulder girdles and arms hanged relaxed by their sides, while

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cohort ((n=150))</th>
<th>Male ((n=61))</th>
<th>Female ((n=89))</th>
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<td>Age (years)</td>
<td>22.3±3.6</td>
<td>22.7±3.6</td>
<td>22.5±3.6</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71±0.09</td>
<td>1.70±0.07</td>
<td>1.66±0.06</td>
</tr>
<tr>
<td>Range (m)</td>
<td>1.49–1.96</td>
<td>1.62–1.96</td>
<td>1.49–1.89</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>70.1±14.4</td>
<td>79.1±14.8</td>
<td>63.8±11.1</td>
</tr>
<tr>
<td>Range (kg)</td>
<td>45.0–128.0</td>
<td>53.3–128.3</td>
<td>45.0–85.5</td>
</tr>
</tbody>
</table>

---

**Table 1: Cohort demographic measures shown as mean±1 standard deviation**
their body weight was distributed evenly over both feet. The assumed position was not guided by the radiographer, and postpositioning movements were kept to a minimum. All radiographs were taken by the same radiographer and digital capturing unit. The principal researcher classified all modified Takeshima/Herbst Method curvatures on standard radiographic software (Genesis OmniVue® Genesis Digital Imaging, Inc., Los Angeles, CA, USA), with all images digitized at a scale of 1.0 then printed for Centroid classification.

Modified Takeshima/Herbst method

The Takeshima and Herbst methods have been combined, as both individual visual methods complement each other's subtype classification criteria. A continuous posterior vertebral body line (PVBL) was drawn connecting the posterior inferior corner of the C2 vertebral body to the posterior superior corner of the C7 vertebral body. Intervertebral disc lines (IVDL) were established within the intervertebral disc spaces from C2/3 to C6/7 by drawing lines that equally transected the intervertebral disc along its anterior to posterior axis. The five transecting lines were interpreted depending on their visual convergence or divergence posteriorly to the PVBL. The PVBL CSh and IVDL alignments were compared to the subtype classification guidelines to finalize classification. In the modified Takeshima/Herbst method subtype classification guidelines. L-type: The PVBL CSh is lordotic, all the IVDL converge posteriorly. St-type: The PVBL CSh indicates linearity, all the IVDL are parallel. Gk-type: The PVBL CSh is kyphotic, all the IVDL diverge posteriorly. S-type: The upper sub-axial spines (C2/C4) PVBL CSh is lordotic while the lower sub-axial spine (C5/C7) is kyphotic. The upper sub-axial IVDL converge posteriorly, the lower sub-axial IVDL converge posteriorly. RS-type: The upper sub-axial spines (C2/C4) PVBL CSh is kyphotic while the lower sub-axial spine (C5/C7) is lordotic. The upper sub-axial IVDL converge posteriorly while the lower sub-axial IVDL converge posteriorly.

Centroid method

The Centroid method utilizes a combination of numerical and visualization techniques to classify alignment. Centroids represent the intersection point of two lines within the vertebral bodies of C3-C6. The first line connected the anterior inferior corner of the vertebral body to the posterior superior corner of the vertebral body while the second line connected the anterior superior corner of the vertebral body to the posterior inferior corner of the vertebral body. The C2-C7 Centroid determination line (CDL) was generated by connecting two points. The first point was located centrally on the inferior endplate of C2 while the second point was located centrally on the superior endplate of C7. Measured relationships of the Centroids to the CDL are outlined within the subtype classification guidelines. In the Centroid method, subtype classification guidelines. L-type: All Centroids are located anteriorly to the CDL; at least, one Centroid is ≥2 mm from the CDL. St-type: The Centroids can be located anterior or posteriorly to the CDL; however, all Centroids must lay ≥2 mm from the CDL. Gk-type: All Centroids are located posteriorly to the CDL; at least, one Centroid is ≥2 mm from the CDL. S-type: One upper cervical Centroid must be located anteriorly to the CDL while one lower cervical Centroid must be located posteriorly to the CDL. One Centroid regardless of location must be ≥2 mm from the CDL. RS-type: One upper cervical Centroid must be located posteriorly to the CDL while one lower cervical Centroid must be located anteriorly to the CDL. One Centroid regardless of location must be ≥2 mm from the CDL [Figure 2].

Relative rotation angle

When methodological inconsistency occurred, five individual RRA were generated from C2/3 to C6/7. These intersegmental angles are measured at the intersection of consecutive PVBLs [Figure 3].

Final classification subtyping

Subtyping was performed separately on different copies of the same radiographs to limit the influence of previously determined classifications derived from the alternative method. Classification difficulties occurred when methods tended not to agree. Selecting a specific subtype to represent the participant involved simultaneously reviewing both marked radiographs in conjunction with the RRA measures, then comparing the collective findings with their relative guidelines. Final subtype classification was only achievable once the RRA flexion and extension findings were matched with the guidelines.

Statistical evaluation of methodological agreement

Cohen's kappa coefficient (κ) was used to assess the level of agreement between the two methods, taking into account the agreement occurring by chance. The magnitude of the kappa coefficient was evaluated according to the criteria established by Landis and Koch. (< 0 no agreement, 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–1 almost perfect agreement).
Figure 2: Centroid method subtype classification guidelines

Figure 3: C4/5 relative rotation angle guidelines. Segmental flexion (positive angle) is indicated when the inferior posterior vertebral body line projects posteriorly after intersecting the superior posterior vertebral body line. Segments measuring ≤2° were considered parallel. Segmental extension (negative angle) is indicated when the inferior posterior vertebral body line projects anteriorly after intersecting the superior posterior vertebral body line.

RESULTS

Subtype numbers and percentages for each sex and the cohort as a whole are outlined within Table 2. The largest percentage (34.0%) of the cohort was classified in the L-type.

Statistical evaluation of methodological agreement

Methodological consistency occurred on 94 (67.7%) occasions while methods tended not to agree 56 (37.3%) times. When agreement by chance was taken into account only a moderate level of agreement was identified, $\kappa = 0.531$ (53.1%).

The method used to select each participant’s subtype is outlined in Table 3. Methodological consistency was greater within the L and CK-type curves. Conversely, in approximately 60% of cases, S, Ss, and RS-types were selected by a single method alone [Figures 4-6]. In cases where a subtype was classified by only a single method, Tables 4 and 5 show how the classification of each subtype differs between the two methods. Figures 4-6 provide specific examples of single method subtype classifications.

DISCUSSION

Cervical spine subtype classification methods must be reliable, interchangeable, and reduce bias. Several investigators have performed comparative and reliability studies on commonly performed cervical angular measures. However, this is the first study to our knowledge that has compared and contrasted established cervical subtype classification methods within an asymptomatic population. When comparing cervical subtype classification methods, it was surprising to observe only a moderate level of agreement (53.1%). Our findings indicate that both methods display bias, the Centroid method selects St-types over S and RS-types whereas the modified Takahashi/Herbst method selects S and RS-types over St-types [Tables 4 and 5]. Therefore, depending upon the classification method used to assess a single presentation, different cervical subtypes may be selected. This has implications for clinical decision-making.

The three factors responsible for most of the inconsistencies in subtype classification were, (1) segmental flexion (their number, location, and degree), (2) the large segmental extension angles located at the upper (C2/3) and lower (C6/7) sub-axial spine, and (3) the S and RS-type transitional region (either C3/4, C4/5 or C5/6) between the upper and lower sub-axial cervical curve. In cases where inconsistencies arose, further investigation of the radiographs RRA flexion and extension findings and subtyping guidelines was undertaken. A classification decision was reached when the collective methodological and RRA evidence supporting the selection of one method’s subtype could not be refuted by the alternative.

Consistency between classification methods appears to be enhanced when there is a greater number of extended (L-type 90.2%) or flexed (CK-type 85.7%) segments in sequence. Importantly, complete segmental extension is only observed within the L-type classification, a fact that appeared to account for the greater consistency between the two methods when classifying this subtype. Conversely, none of the CK-type classifications displayed complete segmental flexion throughout the entire cervical spine. Our data indicate that the upper (C2/3) and lower (C6/7) segments within the
Table 2: The number of female (n=69; 59.3%) and male (n=51; 40.7%) participants within each of the subtype classifications

<table>
<thead>
<tr>
<th>Subtype</th>
<th>Female cohort (%)</th>
<th>Percentage of total cohort</th>
<th>Male cohort (%)</th>
<th>Percentage of total cohort</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-type</td>
<td>22 (24.8)</td>
<td>14.7</td>
<td>29 (47.5)</td>
<td>19.3</td>
<td>51 (34.0)</td>
</tr>
<tr>
<td>S-type</td>
<td>23 (25.8)</td>
<td>15.3</td>
<td>14 (22.9)</td>
<td>9.3</td>
<td>37 (24.6)</td>
</tr>
<tr>
<td>GK-type</td>
<td>29 (29.2)</td>
<td>17.3</td>
<td>2 (3.3)</td>
<td>1.3</td>
<td>31 (20.8)</td>
</tr>
<tr>
<td>S-type</td>
<td>9 (10.1)</td>
<td>6.1</td>
<td>4 (6.6)</td>
<td>2.6</td>
<td>13 (8.7)</td>
</tr>
<tr>
<td>RS-type</td>
<td>9 (10.1)</td>
<td>6.1</td>
<td>12 (19.7)</td>
<td>8.0</td>
<td>21 (14.1)</td>
</tr>
</tbody>
</table>

Data presented as n (% of cohort). GK - Global kyphotic; L - Lordotic; St - Straight; S - Sigmoidal; RS - Reverse sigmoidal

Table 3: Quantification of cervical subtype classifications according to each method

<table>
<thead>
<tr>
<th>Subtype</th>
<th>Selected by both methods (%)</th>
<th>Selected only by Centroid method</th>
<th>Selected only by modified Takeshima/Herbst method</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-type</td>
<td>46 (90.2)</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>S-type</td>
<td>13 (35.1)</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>GK-type</td>
<td>24 (85.7)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>S-type</td>
<td>4 (30.8)</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>RS-type</td>
<td>7 (33.3)</td>
<td>1</td>
<td>13</td>
</tr>
</tbody>
</table>

GK - Global kyphotic; L - Lordotic; St - Straight; S - Sigmoidal; RS - Reverse sigmoidal

Figure 4: Global kyphotic type selected by the Centroid method and how the modified Takeshima/Herbst method selected and classified the same curvature as a reverse sigmoidal.

GK-type typically display extension. The combination of extended and flexed cervical segments in a region of the vertebral column that should display predominately extension may contribute to the moderate level of classification inconsistencies observed between the two methods. Specific differences in the classification guidelines for the nonlordotic subtypes resulted in classification inconsistencies in approximately two-thirds of the participants demonstrating St, S, and RS-types.

The Centroid method [Figure 2] uses numerical distances and visual placement of the Centroids to a CDL whereas the modified Takeshima/Herbst method [Figure 1] uses visual recognition of the PVBL's CSL and the posterior convergence or divergence of the IVDLs. PVBM is a highly reliable spinal landmark however, the vertebral endplates exhibit inter-participant angular variability.[14] The Cobb method reliably uses vertebral endplates to assess and regularly report cervical angular measures.[6] Our findings are consistent with those from Ohara et al.,[6] who concluded correlations were strong within all angular measures related to the L-type and weaker among the nonlordotic classifications.

The Centroid method's classification guideline for the GK-type allowed the identification of all the Centroids posteriorly to the CDL with one Centroid ±2 mm from the CDL indicating all GK-type cases. Conversely, the modified Takeshima/Herbst method appeared to be influenced by the segmental extension located at the upper (C2/3) or lower (C6/7) segments. Accordingly, the PVBL and posteriorly converged C2/3 on C3/4 or C5/6 on C6/7 IVDL were identified as either an S or RS-type [Figure 4]. This no doubt contributed to the modified Takeshima/Herbst methods over selecting these two subtypes and under selecting the GK-type. However, in pronounced
Table 4: Subtypes selected by the Centroid method and how the alternative method selected and classified the same curvature

<table>
<thead>
<tr>
<th>Selected only by the Centroid method</th>
<th>Total</th>
<th>How the modified Takeshima/Herbst method select the same curve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L-type</td>
</tr>
<tr>
<td>L-type</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>S-type</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>GK-type</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>S-type</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>RS-type</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

GK = Global kyphotic; L = Lordotic; S = Straight; RS = Reverse sigmoidal

Table 5: Subtypes selected by the modified Takeshima/Herbst method and how the alternative method selected and classified the same curvature

<table>
<thead>
<tr>
<th>Selected only by the modified Takeshima/Herbst method</th>
<th>Total</th>
<th>How the Centroid method select the same curve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L-type</td>
</tr>
<tr>
<td>L-type</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>S-type</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>GK-type</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>S-type</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>RS-type</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

GK = Global kyphotic; L = Lordotic; S = Straight; RS = Reverse sigmoidal

S or RS-type curves, the consistency between each method increases markedly. The Centroid method has a propensity to over select the number of St-type classifications within shallow S and RS-type curvatures, leading to an under selection within these two classifications [Table 4]. The Centroids within these shallow sigmoidal types fell either anterior or posterior to the CDL but at no location were the Centroids ≥2 mm from the CDL.

While classifying the St-type one problem was that all cases with Centroid locations ≤2 mm from the CDL were selected into this subtype. In contrast, the extremely rigid St-type guidelines for the modified Takeshima/Herbst method allows only a linear PVBL CSH and parallel IVDL to be selected, potentially contributing to a smaller number of this subtype selected by this method [Tables 4 and 5]. Conversely, within shallow curvatures, these small visual discrepancies in the PVBL and the nonparallel IVDL appear to allow over selection of S and RS-type classifications by the modified Takeshima/Herbst method [Table 4]. Anteriorly located Centroids (at least one Centroid ≥2 mm from the CDL) permitted an L-type classification [Figure 2]. However, when inconsistencies arose, the modified Takeshima/Herbst method classified these curves as S or RS-types [Table 4].

In contrast, an opposite scenario was observed when using the modified Takeshima/Herbst method [Table 5] whereby the PVBL CSH and the nonparallel IVDL allowed the selection of S or RS-types rather than the Centroid method’s St-type classification [Figures 5 and 6]. Our research highlights that shallow sigmoidal curves with small focal kyphotic regions are difficult to classify consistently with either method.

Figure 6: Reverse sigmoidal type selected by the modified Takeshima/Herbst method and how the Centroid method selected and classified the same curvature as a straight

A potential limitation of the current study was that only one researcher was responsible for classifying all subtypes through both methods and the final subtype selection. To mitigate any potential errors, all images were assessed on three occasions to formulate the final selected subtype. This comparative methodological investigation has revealed the likelihood for considerable differences in the classification of certain cervical subtypes depending on which one of the two methods is applied. The Centroid method is well suited to determine L, St, and GK-types, whereas, the modified Takeshima/Herbst method is suited to determine L, GK, S, and RS-types. The Centroid methods use of the Centroid to CDL measurement adds a level of numerical analysis not present within the modified Takeshima/Herbst method, however the visualization of the PVBL and IVDL...
utilized by the modified Takehima/Herbst method offers an alternative alignment perspective not offered by the Centroid method.

CONCLUSION

Our research reinforces the need for multimodal contrasting in conjunction with the RRA measure to accurately assess and report non-lordotic subtypes. Clinical decision-making and prognostic determination require establishing precise baseline cervical subtype classifications to permit reliable pre- and post-image contrasting during postintervention appraisal. With an increasing trend toward non-lordotic alignment,\(^{18,20}\) evidence-based care will encourage the reporting of therapeutic interventions and outcomes with even increasing alignment accuracy. To increase reliability, validity, and cross correlation of clinical and research findings, our study highlights the need for establishing a standardized multi-method approach to classify sagittal cervical subtypes.

Key points

- Non-lordotic subtypes were demonstrated by 99 out of the 150 (66.0%) participants
- Methodological consistency occurred on 94 (62.7%) occasions while inconsistency was identified 56 (37.3%) times. When agreement by chance was taken into account, only a moderate level of agreement was identified, \(\kappa = 0.531\) (53.1%)
- Consistency was higher while classifying the L and Gk-types. Conversely, classification of non-lordotic patterns varies depending on the method selected
- The challenges presented to clinicians to correctly classify cervical sagittal alignment may be reduced when a multi-method approach is undertaken, thus strengthening classification validity
- A classification decision in cases of inconsistency can be reached when methodological and RRA measures are considered together
- Our research provided a detailed descriptive appraisal that could be used to standardize cervical alignment classification for reporting purposes.

Acknowledgment

The authors would like to thank,

- Rebecca Mellifont (PhD) for her assistance with the project.
- Dr. David Shahar, DC for performing radiological services.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.


40. Silva AG, Pant TD, Johnson MJ. Variability of angular measurements of head posture within a session, within a day, and over a 7-day period in healthy participants. Physiother Theory Pract 2011;27:503-11.


42. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
Appendix 2: Human Ethics Approval.

2 April 2014

Kelly Stewart
Acting Manager, Office of Research
Tel: +61 7 5459 4574
Fax: +61 7 5459 4727
Email: humanethics@usc.edu.au

Mr Lee Daffin
Dr Rebecca Mellifont
Dr Mark Sayers
Faculty of Science, Health, Education and Engineering

Dear Lee, Rebecca and Mark

Expeditied ethics approval for research project: The impact of the cervical lordosis on postural sway parameters in asymptomatic subjects: An evaluation and comparison between unloaded and loaded stance (5/14/607)

This letter is to confirm that on 2 April 2014, following review of the application for ethics approval of the research project, The impact of the cervical lordosis on postural sway parameters in asymptomatic subjects: An evaluation and comparison between unloaded and loaded stance (5/14/607), the Acting Chairperson of the Human Research Ethics Committee of the University of the Sunshine Coast granted expedited ethics approval for the project.

The Human Research Ethics Committee will review the Chairperson's grant of approval and the conditions of approval at its next meeting and, should there be any variation of the conditions of approval, you will be informed as soon as practicable.

The period of ethics approval is from 2 April 2014 to 15 February 2016.

Could you please note that the ethics approval number for the project is HREC: (5/14/607). This number should be quoted in your Research Project Information Sheet and in any written communication when you are recruiting participants.

The standard conditions of ethics approval are listed overleaf. If you have any queries in relation to this ethics approval or if you require further information please contact the Research Ethics Officer by email at humanethics@usc.edu.au or by telephone on +61 7 5459 4574 / 5430 2823.

I wish you well with the success of your project.

Yours sincerely

Kelly Stewart
Acting Manager, Office of Research

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Facsimile +61 7 5430 1111 | Australia | Sippy Downs Qld 4556
	| Australia |

IONISING RADIATION DOSE CALCULATION FOR CHIROPORATIC RESEARCH PROPOSAL

University of the Sunshine Coast Queensland
School Organisational Unit: SHSS, PoSHHE

Topic: As the degree of cervical lordosis reduces in asymptomatic subjects do postural away parameters change: A comparison between unloaded and loaded stance.

Investigators: Lee Daffin, BSc, M.Chiro., Dr Rebecca Mellfont, Dr Mark Sayers

Attention: Dr. David Shalar.
Director, Dr. Posture
PO Box 741
SIPPY DOWNS Q 456

The above study and similar studies to follow involve the use of ionising radiation exposure to volunteers participating in the studies. The current study will require volunteers to have AP and Lat cervical radiography using the techniques of Harrison et al (2003).

Subsequent studies within the University will require volunteers to have the above Cervical radiography plus: AP Cervico-Thoracic, Lat Thoracic, Lat Lumbar and AP Lumbo-Pelvic. These exposures are assumed to be for research purposes only and are not part of on-going therapy of individuals participating as volunteers. All such radiation exposure must be delivered in accordance with the Australian Radiation and Nuclear Safety Agency CODE OF PRACTICE, Exposure of Humans to Ionising Radiation for Research Purposes, Radiation Protection Series Publication No. 8, May 2005.

Figures for whole body effective dose and critical organ dose for each of the views are tabulated below. Dose calculations have been performed according to the methods and data published in Appendix 1 and 2 of International Commission for Radiological Protection: Publication No 34, Protection of the Patient in Diagnostic Radiology

The following radiographic technique factors have been incorporated into the calculations:

- Dose calculations are based on the patient being a standard morphology of 70kg adult, AP thickness of 26 cm and Lateral thickness of 35 cm. Some variation in actual dose will occur if subjects diverge markedly from this standard.
- Standard Focus to Image Receptor Distance (FFD) of 180cm for all views and a patient to image receptor offset of 5 cm has been applied.
- Focus to Skin Distance AP = 180 (24-5) = 159 cm
- Focus to Skin Distance LAT = 180 (35-5) = 140 cm
- Focus to Skin Distance LAT Cx = 180 (24-4) = 152 cm
- Characteristics of the X-ray beam as follows and cross checked with compliance testing data from Dr. Shalar’s chiropractic X-ray unit:
  - Medium frequency constant potential output:
    - HVL: 3.6 mm Al at 75 kV
    - Radiation output assessed at 0.024 mGy per mAs at 100cm at 75 kV
Radiographic parameters for each view as follows based on commonly applied good practice and standard CR/Tlm speed of 400:
- LAT Cervical: 75 kV/20 mAs;
- AP Cervical: 75 kV/20 mAs;
- AP Cervico-Thoracic: 75 kV/40 mAs;
- LAT Thoracic: 75 kV/80 mAs;
- AP Lumbo-Pelvic: 75 kV/60 mAs;
- LAT Lumbar: 100 kV/80 mAs

<table>
<thead>
<tr>
<th>Radiographic View</th>
<th>Air Kerma at 1m (Gy)</th>
<th>Entrance Air Kerma (Gy)</th>
<th>Absorbed Dose per Gy entrance Kerma (mGy)</th>
<th>Absorbed Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAT Cervical</td>
<td>0.0005</td>
<td>0.00021</td>
<td>29</td>
<td>0.006</td>
</tr>
<tr>
<td>AP Cervical</td>
<td>0.0005</td>
<td>0.00019</td>
<td>37</td>
<td>0.007</td>
</tr>
<tr>
<td>AP Thoracic</td>
<td>0.0009</td>
<td>0.0033</td>
<td>70/55</td>
<td>0.027/0.021</td>
</tr>
<tr>
<td>LAT Thoracic</td>
<td>0.002</td>
<td>0.0068</td>
<td>60/55</td>
<td>0.059/0.054</td>
</tr>
<tr>
<td>LAT Lumbar</td>
<td>0.001</td>
<td>0.0026</td>
<td>66</td>
<td>0.017</td>
</tr>
<tr>
<td>AP Lumbo-Pelvic</td>
<td>0.0014</td>
<td>0.00357</td>
<td>137</td>
<td>0.078</td>
</tr>
<tr>
<td>TOTAL DOSE</td>
<td></td>
<td></td>
<td></td>
<td>0.194/0.183</td>
</tr>
</tbody>
</table>

Where two values are given the first value is for females, the second value is for males.

Table 2: Thyroid Absorbed Dose per View.

<table>
<thead>
<tr>
<th>Radiographic View</th>
<th>Air Kerma at 1m (Gy)</th>
<th>Entrance Air Kerma (Gy)</th>
<th>Absorbed Dose per Gy entrance Kerma (mGy)</th>
<th>Absorbed Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAT Cervical</td>
<td>0.0005</td>
<td>0.00021</td>
<td>58</td>
<td>0.012</td>
</tr>
<tr>
<td>AP Cervical</td>
<td>0.0005</td>
<td>0.00019</td>
<td>991</td>
<td>0.188</td>
</tr>
<tr>
<td>AP Thoracic</td>
<td>0.0009</td>
<td>0.0038</td>
<td>155</td>
<td>0.059</td>
</tr>
<tr>
<td>LAT Thoracic</td>
<td>0.002</td>
<td>0.0068</td>
<td>14</td>
<td>0.014</td>
</tr>
<tr>
<td>LAT Lumbar</td>
<td>0.005</td>
<td>0.0026</td>
<td>0.01</td>
<td>0.0000026</td>
</tr>
<tr>
<td>AP Lumbo-Pelvic</td>
<td>0.0014</td>
<td>0.0057</td>
<td>0.01</td>
<td>0.0000057</td>
</tr>
<tr>
<td>TOTAL DOSE</td>
<td></td>
<td></td>
<td></td>
<td>0.273</td>
</tr>
</tbody>
</table>

Table 3: Female Breast Absorbed Dose per View.

<table>
<thead>
<tr>
<th>Radiographic View</th>
<th>Air Kerma at 1m (Gy)</th>
<th>Entrance Air Kerma (Gy)</th>
<th>Absorbed Dose per Gy entrance Kerma (mGy)</th>
<th>Absorbed Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAT Cervical</td>
<td>0.0005</td>
<td>0.00021</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>AP Cervical</td>
<td>0.0005</td>
<td>0.00019</td>
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<td>0</td>
</tr>
<tr>
<td>AP Thoracic</td>
<td>0.0009</td>
<td>0.0033</td>
<td>945</td>
<td>0.359</td>
</tr>
<tr>
<td>LAT Thoracic</td>
<td>0.002</td>
<td>0.0068</td>
<td>17</td>
<td>0.017</td>
</tr>
<tr>
<td>LAT Lumbar</td>
<td>0.005</td>
<td>0.0026</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>AP Lumbo-Pelvic</td>
<td>0.0014</td>
<td>0.0057</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL DOSE</td>
<td></td>
<td></td>
<td></td>
<td>0.376</td>
</tr>
</tbody>
</table>
Table 4: Ovary Absorbed Dose per View.

<table>
<thead>
<tr>
<th>Radiographic View</th>
<th>Air Kerma at lm (Gy)</th>
<th>Entrance Air Kerma (Gy)</th>
<th>Absorbed Dose per Gy entrance Kerma (mGy)</th>
<th>Absorbed Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAT Cervical</td>
<td>0.0005</td>
<td>0.00021</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>AP Cervical</td>
<td>0.0005</td>
<td>0.00019</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>AP Thoracic</td>
<td>0.0009</td>
<td>0.00018</td>
<td>3.1</td>
<td>0.0012</td>
</tr>
<tr>
<td>LAT Thoracic</td>
<td>0.002</td>
<td>0.00096</td>
<td>0.7</td>
<td>0.00069</td>
</tr>
<tr>
<td>LAT Lumbar</td>
<td>0.005</td>
<td>0.0026</td>
<td>110</td>
<td>0.283</td>
</tr>
<tr>
<td>AP Lumbo-Pelvic</td>
<td>0.0014</td>
<td>0.00057</td>
<td>380</td>
<td>0.137</td>
</tr>
<tr>
<td>TOTAL DOSE</td>
<td></td>
<td></td>
<td></td>
<td>0.423</td>
</tr>
</tbody>
</table>

Table 5: Testes Absorbed Dose per View.

<table>
<thead>
<tr>
<th>Radiographic View</th>
<th>Air Kerma at lm (Gy)</th>
<th>Entrance Air Kerma (Gy)</th>
<th>Absorbed Dose per Gy entrance Kerma (mGy)</th>
<th>Absorbed Dose (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAT Cervical</td>
<td>0.0005</td>
<td>0.00021</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>AP Cervical</td>
<td>0.0005</td>
<td>0.00019</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>AP Thoracic</td>
<td>0.0009</td>
<td>0.00018</td>
<td>3.1</td>
<td>0.0012</td>
</tr>
<tr>
<td>LAT Thoracic</td>
<td>0.002</td>
<td>0.00096</td>
<td>0.7</td>
<td>0.00069</td>
</tr>
<tr>
<td>LAT Lumbar</td>
<td>0.005</td>
<td>0.0026</td>
<td>110</td>
<td>0.283</td>
</tr>
<tr>
<td>AP Lumbo-Pelvic</td>
<td>0.0014</td>
<td>0.00057</td>
<td>380</td>
<td>0.137</td>
</tr>
<tr>
<td>TOTAL DOSE</td>
<td></td>
<td></td>
<td></td>
<td>0.411</td>
</tr>
</tbody>
</table>

Conclusion.

The expected dose for a single chiropractic series in the research proposal is well below the dose constraints applied by the Australian Code of Practice. The total dose for multiple examinations can be summed by adding the dose for each proposed series; however, the following guideline from the Code of Practice is brought to your attention: "The radiation doses to the research participants must be kept to the minimum level practicable".

The table of dose constraints for research purposes from the ARFANSA Code of Practice is illustrated for reference on the following page. Please feel free to contact me for any further advice regarding radiation exposure in this or other projects.

Yours sincerely,

GAMMASONICS INSTITUTE FOR MEDICAL RESEARCH PTY LTD

David Leslie MIR, MARPS, BHSc (Adel)
Manager, Compliance Testing Division

Professor Carl Munoz- Ferrada
Director

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1 CODE OF PRACTICE Exposure of Humans to Ionising Radiation for Research Purposes Radiation Protection Series Publication No. 8 May 2005 ARFANSA
Table 1. Dose Constraints for Participants in Research

<table>
<thead>
<tr>
<th>Participant Category</th>
<th>Dose Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults</td>
<td></td>
</tr>
<tr>
<td>total effective dose</td>
<td>- in any year</td>
</tr>
<tr>
<td></td>
<td>- over 5 years</td>
</tr>
<tr>
<td>total effective dose in adult with life expectancy less than five years</td>
<td>- in any year</td>
</tr>
<tr>
<td>equivalent dose to skin</td>
<td>- in any year</td>
</tr>
<tr>
<td>averaged over 1 cm(^2)</td>
<td></td>
</tr>
<tr>
<td>equivalent dose to any other organ or tissue</td>
<td>- in any year</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Children and fetuses</td>
<td></td>
</tr>
<tr>
<td>Total effective dose to age 18 years,</td>
<td>5 mSv</td>
</tr>
<tr>
<td>- Subject to:</td>
<td></td>
</tr>
<tr>
<td>• Effective dose from conception to birth; and</td>
<td>0.1 mSv</td>
</tr>
<tr>
<td>• Effective dose in any year from birth to 18 years.</td>
<td>0.5 mSv</td>
</tr>
<tr>
<td>Total equivalent dose to age 18 years to any organ or tissue</td>
<td>100 mSv</td>
</tr>
</tbody>
</table>

\(^a\) A dose constraint for research participants specifies a maximum dose with which it should be possible to comply in normal circumstances and it is intended to apply to radiation which is in addition to that received as part of normal clinical management. Dose constraints apply to diagnostic investigations not radiation therapy.

\(^b\) The dose constraint applies to the sum, over the relevant period, of doses received from external exposure and the 50-year committed dose (to age 70 years for children) from intakes over the same period.

\(^c\) When all the research participants are within the following specified age limits, the following total effective dose constraints apply:
   - for adult 60 years or more - in any year - 8 mSv and
   - for adult 70 years or more - in any year - 12 mSv.

\(^d\) Derived from Table 3.1 of ICRP85 – factor of 10 below the threshold of 2 Sv for early transient erythema.

\(^e\) Derived from Table 3.1 of ICRP85 – factor of 10 below the threshold of 1 Sv for detectable lens opacity.
PhD research aims to investigate common neck pain. A former Chiropractor has started detailed spinal posture research at the University of the Sunshine Coast to probe the problem of neck pain. PhD student Lee Daffin, 45, of Conondale, aims to uncover the neurological mechanisms responsible for the development of non-specific neck pain. Non-specific neck pain is pain not caused by trauma, while neurological relates to the nervous system. Mr Daffin said previous research has suggested that 80 percent of the population would experience episodes of this health issue during their lives. “Modern society is cultivating a generation that will never develop a normal neck curvature,” he said. “Forward head posture is the universal head position observed in societies globally, predominantly due to the increase in computer usage. “I’m investigating the neck’s curvature and the mechanisms involved in upright balance control. The aim is to develop a clinical test to identify individuals who may develop NSNP before they develop this lifelong problem.” Mr Daffin has 10 years’ clinical experience and tutor’s anatomy at USC. He is seeking 150 people aged 18 to 30 for the project. For details (Lee.Daffin@research.usc.edu.au).
Appendix 5: Ethics Approval, Whyfitness Magazine Recruitment.

7 April 2014

Kelly Stewart
Acting Manager, Office of Research
Tel: +61 7 5459 4574
Email: humanethics@usc.edu.au

F22265

Mr Lee Daffin
Dr Rebecca Mellifont
Dr Mark Sayers
University of the Sunshine Coast

Dear Lee, Rebecca and Mark

Expedited ethics approval for amended research project: The impact of the cervical lordosis on postural sway parameters in asymptomatic subjects: An evaluation and comparison between unloaded and loaded stance (S/14/607)

This letter is to confirm that on 7 April 2014, the Acting Chairperson of the Human Research Ethics Committee of the University of the Sunshine Coast granted expedited ethics approval for an amendment to the above project.

The amendment of the project refers to the wording to be used in a recruitment advertisement in Whyfitness magazine.

The conditions for ethics approval for this project as outlined in our letter of 2 April 2014 continue to apply.

If you have any queries in relation to this ethics approval or if you require further information please contact a Research Ethics Officer by email at humanethics@usc.edu.au or by telephone on +61 7 5459 4574 or 5430 2823.

Yours sincerely

Kelly Stewart
Acting Manager, Office of Research
Appendix 6: WhyFitness Magazine Recruitment.

Neck Pain: How you can be part of the solution.

You never know which direction life will take you. Four years ago, Lee Daffin operated a private chiropractic clinic in the Sunshine Coast hinterland. Following a spinal cord injury and the paralysis of his right leg, he was left physically unable to practise his profession. During his recovery, there was a lot of soul searching around what he would do with his life if he was unable to continue as a Chiropractor. His one true passion was academia; he loved it. Lee now works as a tutor at the University of the Sunshine Coast and has just been confirmed as a PhD candidate. Non-specific neck pain affects between 40 to 80 per cent of the population and costs the global community billions. Lee will be investigating the relationship between our neck’s curvature and the neurological control of balance. His aim is to investigate characteristics that are representative of healthy spinal function. Ultimately, Lee would like this information to be used to assist health practitioners to identify at-risk individuals, however this preliminary study will target healthy individuals. Accordingly, Lee is looking for motivated healthy participants for his study. To be considered, you would need to be 18 to 30 years old, with no history of spinal problems. As a participant in the study, you would be helping Lee to discover if these characteristics exist. The only physical requirement is the ability to stand still. By participating, you will also receive an insight into how your spine is aging and how your nervous system controls it. This research has been approved by the USC Human Research Ethics Committee (protocol S/14/607).
ISSUE 11
ADVERTISING
APPROVAL FORM

Please carefully recheck that all content details are correct. If all is correct, please fax or print/scan and email to us your signed approval to allow print production to proceed. If alterations are required, please clearly specify these on this copy and return fax to us on 07 5302 6609 or print/scan and email to jen@whyfitness.com.au

Please note: Our fully approved material deadline is FRIDAY 11 APRIL. If we receive no feedback/changes before that time, the artwork, as it appears below, will be deemed to be approved for inclusion in Issue 11 of Why Fitness Magazine.

PLEASE FAX TO 07 5302 6609
OR PRINT/SCAN AND EMAIL TO
jen@whyfitness.com.au

CLIENT   LEE DAFFIN
AD SIZE   FEATURE

SIGNED

DATE      11 4 14
CONCEPT   01

☑ CORRECT  Proceed to print
☐ EDITS REQUIRED
Make changes and re-supply proof

It is the responsibility of the client to thoroughly recheck that all advertisement content is accurate and correct prior to publishing. Why Fitness Magazine bears no responsibility for incorrect material reproduced at time of print.

SCENE 1

You never know which direction life will take you. Four years ago, Lee Daffin operated a private chiropractic clinic in the Sunshine Coast hinterland. Following a spinal cord injury and the paralysis of his right leg, he was left physically unable to practice his profession. During his recovery, there was a lot of soul searching around what he would do with his life. Since he was unable to continue as a chiropractor, he took one true passion - academic - and now works as a tutor at the University of the Sunshine Coast and has just been confirmed as a PhD candidate.

Non-specific neck pain affects between 40 to 80 per cent of the population and costs the global community billions. Lee will be investigating the relationship between our neck’s curvature and the neurological control of balance. He aims to investigate characteristics that are representative of healthy spinal function. Ultimately, Lee would like his information to be used to assist health practitioners to identify at-risk individuals; however, this preliminary study will target healthy individuals.

Accordingly, Lee is looking for motivated healthy participants for his study. To be considered, you would need to be 18 to 30 years old, with no history of spinal problems. As a participant in this study, you would be helping Lee to discover if these characteristics exist. The only physical requirement is the ability to stand still. By participating, you will also receive an insight into how your spine is aging and how your nervous system controls it. This research has been approved by the University of the Sunshine Coast Human Research Ethics Committee (protocol S/14/007).

If you are interested in finding out more about the study, please contact Lee at Lee.Daffin@research.usc.edu.au.

Ultimately Lee would like this information to be used to assist health practitioners to identify at-risk individuals, however this preliminary study will target healthy individuals.
Appendix 7: WhyFitness Magazine, Seminar.

As part of the advertising package purchased through WhyFitness Magazine a fitness seminar was organised in early May 2014 to coincide with the launch of issue 11, in which I had advertised. The seminar was held at a local surf club and all advertisers had a stand displaying their fitness products or services. The photograph depicts the layout of the exhibit I occupied during the WhyFitness seminar. No participants came forward through this endeavour.
Appendix 8: Ethics Approval, USC Electronic Noticeboard Recruitment.

6 May 2014

Kelly Stewart
Acting Manager, Office of Research
Tel: +61 7 5439 4574
Email: humanethics@usc.edu.au

F22265

Mr Lee Daffin
Dr Rebecca Mellifont
Dr Mark Sayers
University of the Sunshine Coast

Dear Lee, Rebecca and Mark

Expedited ethics approval for amended research project: The impact of the cervical lordosis on postural sway parameters in asymptomatic subjects: An evaluation and comparison between unloaded and loaded stance (S/14/607)

This letter is to confirm that on 6 May 2014, the Acting Chairperson of the Human Research Ethics Committee of the University of the Sunshine Coast granted expedited ethics approval for an amendment to the above project.

The amendment refers to approval for recruitment via the USC electronic noticeboards controlled by Student Life and Learning.

The conditions for ethics approval for this project as outlined in our letter of 2 April 2014 continue to apply.

If you have any queries in relation to this ethics approval or if you require further information please contact a Research Ethics Officer by email at humanethics@usc.edu.au or by telephone on +61 7 5439 4574 or 5430 2823.

Yours sincerely

Kelly Stewart
Acting Manager, Office of Research
Appendix 9: USC Electronic Noticeboard Recruitment.

Student Life and Learning now known as The Centre for Support and Advancement of Learning and Teaching (C-SALT) organise notices on large television screens in strategic positions across the university. The notices are on a continual loop and are shown for 15 seconds per viewing. The advertising campaign ran for 2 months, but no participants came forward.

---

**SPINAL RESEARCH**

Help USC Researchers unlock the relationship between spinal curvature, postural control and the development of neck pain.

Are you healthy and aged 18-30?

Would you be willing to volunteer 2 hours of your time to find out more about the way your spine functions?

Participation in research is beneficial to everyone.

For more information contact:

Lee.Daffin@research.usc.edu.au PhD (candidate)
28 July 2014

Michelle Searle
Director, Office of Research
Tel: +61 7 5459 4574
Email: humanethics@usc.edu.au

Mr Lee Dauffin
Dr Rebecca Mellifont
Dr Mark Sayers
University of the Sunshine Coast

Dear Lee, Rebecca and Mark

Expedited ethics approval for amended research project: The impact of the cervical lordosis on postural sway parameters in asymptomatic subjects: An evaluation and comparison between unloaded and loaded stance (S/14/607)

This letter is to confirm that on 28 July 2014, the Acting Chairperson of the Human Research Ethics Committee of the University of the Sunshine Coast granted expedited ethics approval for an amendment to the above project.

The amendment of the project refers to recruiting through the SONAR (Takepart) system managed by the University of the Sunshine Coast.

The conditions for ethics approval for this project as outlined in our letter of 2 April 2014 continue to apply.

If you have any queries in relation to this ethics approval or if you require further information please contact a Research Ethics Officer by email at humanethics@usc.edu.au or by telephone on +61 7 5459 4574 or 5430 2823.

Yours sincerely

Michelle Searle
Director, Office of Research
Appendix 11: USC Web-Based Recruitment SONAR System.

Lee Daffin, PhD (candidate)

Study Name: A short name for the study (100 chars max)

The impact of neck alignment on standing balance control in asymptomatic (pain free) people.

Brief Abstract: A one or two sentence description of the study. This description will be displayed to participants when searching for studies, so include most pertinent details. (255 chars max)

This study will investigate the accuracy of the central nervous system in controlling postural sway by assessing altered neck curvatures (forward head posture) and their effect on sway quality. The aim of this study is to identify whether there is a relationship between neck alignment and postural balance control in pain free individuals, to determine whether neck alignment contributes to the development of non-specific neck pain.

Detailed Description: This description is displayed to the participant when the participant clicks on the study. You can include some basic HTML, such as a carriage-return <>. (15,000 chars max)

This is a face to face study in which the participants will develop a unique understanding of their current health status, structural alignment and an insight into the possible structural issues surrounding their neck now and into the future.

All interested participants will be sent electronically the Ethics approved Project Information package containing a detailed description of all the relevant research information and forms. This can be obtained via e-mailing:

Lee Daffin (Chief Investigator)
PhD Candidate.
Faculty of Science, Health, Education and Engineering
University of the Sunshine Coast
Lee.Daffin@research.usc.edu.au

The increased use of computers and visual materials has resulted in a workforce that is quite sedentary. A number of altered postural states are becoming common within the population.
Flattening of the neck curve and forward head carriage (head jutting forward) are two postural conditions that are increasingly common and considered pathological.

The primary aim of this study is to investigate the relationship between asymptomatic neck alignment and the postural sway parameters the participant produces during quiet stance and loaded (wearing a back pack) scenarios. The secondary aim is to determine several spinal measurement parameters, head tilt, feet position during external photography, thoracic and lumbar curvature and the neck’s range of motion.

The study will be conducted over three sessions:

**Session 1;** will take approximately 45 min, and this session involves much of the ‘paperwork’ associated with the study:

- Inclusion / Exclusion criteria check,
- the completion of Three Health Questionnaires in order to establish your health status,
- a Physical Examination, involving general body motion to determine Scoliosis, Lower Limb Joint Function, Balance Control and Neck Motion
- and Spinal Parameter Measurements taken with the use of a flexible ruler and camera.

Session 1 will be conducted in the USC Motion Analysis Laboratory, found at HG 17.

**Session 2;** will take approximately 15 min, and this session involves:

- Neck X-rays and Spinal Parameter Measurements. These measures are taken in order to provide researchers with baseline positional data on the orientation of your spine to enable stratification within the group and permit comparison to the non-ionising data from Session 3.

Session 2 will be conducted at a local chiropractic clinic for access to the x-ray machine: 2/1 Scholars Drive, Sippy Downs. This is approximately a 7 min walk from University.

**Please Note;**

As a result of the neck radiographs required, subjects will receive a dose of ionising radiation. In accordance with Human Ethics Approval, a Medical Physicist has provided an ionising radiation report. The report outlines methods, parameters and calculated doses likely to be received in this study. The conclusion from the report found “The expected dose for this research proposal is well below the dose constraints applied by the Australian Code of Practice” (ACP).
Session 3;  Approximately 1.5 hours, and this session involves postural testing in the USC Motion Analysis Laboratory. Testing will include:

- Reflective markers placed onto your body for Qualisys Motion Capture Analysis for body positioning throughout the required movements
- You will stand on force platforms during testing to enable analysis of sway characteristics
- and measurement of Spinal Parameter Measurements to determine the validity of the methods and postural variations assumed during testing.

Session 3 will be conducted again at the USC Motion Analysis Laboratory (same location as Session 1).

Postural control requires a variety of sensory inputs that undergo neural integration and central processing with the brain stem and cerebellum to produce upright posture. Chronic neck pain patients consistently display poor, maladaptive sway parameters. If our hypothesis proves true and the research demonstrates a relationship between altered neck alignment in pain free subjects and poorly adapting postural sway parameters, we may be able to use this information to identify objective markers that could be used to indicate individuals that are more likely to develop neck pain in the future. These markers may be useful in developing a preventative clinical measure that can be implemented by musculoskeletal practitioners to clinically identify at risk individuals in the future and direct them to provide appropriate targeted rehabilitation protocols.

*Eligibility Requirements: If there are any restrictions on participating in the study.*
*(245 chars max)*

Participants must be aged 18 to 30 years, physically healthy, asymptomatic (pain free), free from chronic neck pain, with no history of significant physical trauma.

*Duration: Amount of time in minutes the study may take. For face to face sessions, this is the time taken to complete a session, allowing enough time in between participants if multiple sessions are scheduled consecutively.*

The research project consists of 3 Sessions. Sessions are conducted on separate days. There is little to no risk involved in this project as the test protocols are non-invasive and non-strenuous.
Session 1: 45 min, Session 2: 15 min, Session 3: Approximately 1.5 hours.

Total for all three sessions: approx. 2.5 hours

Preparation: Any advance preparation a participant must do. E.g. Do not eat two hours before session.

Prior to the first session, participants may like to complete the health status questionnaires. This will reduce time on campus by 15 minutes. All forms are available in hard copy for completion in the laboratory on the day of testing.

- The Medical Outcomes Study 36-item short-form (SF-36)
- The Neck Disability Index (NDI)
- The Postural Sway Questionnaire (PSQ)

Researchers: Most likely you. Any other people involved.

Lee Daffin (Chief Investigator)
PhD, Candidate.
Faculty of Science, Health, Education and Engineering
University of the Sunshine Coast
Lee.Daffin@research.usc.edu.au

Dr Rebecca Mellifont (Supervisor)
Senior Lecturer in Sport Sciences (Anatomy)
Faculty of Science, Health, Education and Engineering
University of the Sunshine Coast
07 5456 5065

Dr Mark Sayers (Co Supervisor)
Senior Lecturer in Sports Biomechanics
Faculty of Science, Health, Education and Engineering
University of the Sunshine Coast
07 5459 4703

Ethics Approval code: Ethics approval

S/14/607.
Appendix 12: USC Static Research Notification Board, Research Flyer.

University of the Sunshine Coast
Queensland, Australia

Ethics Approval No. HRES (S/14/607)

School of Health and Sport Sciences
Spinal Health and Postural Balance Study

Are you 18 to 30 years old and consider yourself healthy?
Have no Physical / Skeletal problems that you are aware of?

Would you like to participate in a research project and find out how your neck is aging and how well your nervous system controls your balance?

All you will need to do is

✓ Complete 3 Health Screening Questionnaires
✓ Undergo a Physical Examination.
✓ Have your Neck X-rayed from the Front and Side
✓ Have your Balance Assessed in the University’s Motion Capture Lab on the Force Platform

The only physical requirement is to be able to stand on the spot as still as possible!

Why should you get Involved?

You will find out some interesting physical qualities about yourself. You can ask any questions about your spine that you have ever wanted answered.

_all aspects of the project will be conducted by a qualified musculoskeletal practitioner._

PLEASE CONTACT:
Lee Daffin, BSc. (Anatomy), M.Chiro. PhD (Candidate) Lee.Daffin@research.usc.edu.au
Appendix 14: Research Project Information Sheet.

Research Project Information Sheet

HRES: (S/14/607)

Project Title
The impact of cervical lordosis on postural sway parameters in asymptomatic subjects: An evaluation and comparison between unloaded and loaded stance.

Investigators
Lee Daffin, BSc. M.Chiro. PhD (Candidate)
Dr Rebecca Mellifont
Dr Mark Sayers

Participation in the following study is voluntary and participants may withdraw at any stage, without explanation and there will be no consequences as a result.

Background and Aims
The large number of desk-based professions has meant that today’s workforce is quite sedentary. The increased use of computers and visual materials has resulted in a number of altered postural states becoming common within the population. Cervical hypolordosis (flattening of the neck curve) and forward head carriage (head jutting forward) are two postural conditions that are becoming increasingly common and considered pathological. The primary aim of this study is to investigate the relationship between neck angle (asymptomatic cervical lordotic angles) and the postural sway parameters they produce. Data will be collected during quiet stance and loaded (wearing a back pack) scenarios. The secondary aim is to determine whether the direction of initial sway is linked in any way to the side which the head tilts to when the participant is viewed from the front. The study will also investigate the significance of the feet position while undertaking standing posture photographs. The relationship of the central region of the spine’s shape as measured by a flexible ruler to the angle of the neck will also be investigated.

This information along with a variety of other inputs undergoes neural integration and central processing within the brain stem and cerebellum to produce upright posture. Chronic neck pain patients have consistently displayed poor, maladaptive sway parameters. This study will investigate the relationship between altered neck postures in healthy participants and balance control while standing stationary. We hope to be able use the balance control information to develop procedures that could identify healthy individuals that may be at risk of develop neck pain in the future. Early identification could allow health practitioners to prescribe targeted rehabilitation programs that limit the likelihood of neck pain beginning.

Preliminary Health Screening
You will be asked to complete three health questionnaires which will help us assess your suitability for participation in this research. It will take approximately 15 minutes to complete these questionnaires. Participants always have the right to leave a question out when answering a questionnaire.
X-ray Procedures and Acquisition

You will be asked to undergo two neck X-rays, one from the side and one from the front. Five small (4mm diameter) steel markers will be attached with double sided tape to the skin near the ear and base of the neck. These markers will leave impressions on the X-ray that will be used to calculate measurements. The X-rays will be performed standing upright and will take less than 15 minutes to complete.

There will be two standard positions for the radiographs, lateral cervical view (side of neck) and Anterior to Posterior cervical view (front of neck). X-ray positioning and verbal instructions will be conducted in accordance with Harrison et al. (2003). 4mm Steel markers will be positioned on the participants while the X-rays are taken. Lateral cervical view will have 3 markers positioned on the spinous process of the seventh cervical vertebra, the Tragus of the ear and the Canthes, lateral to the eyes orbital margin. Anterior to Posterior cervical view will have markers placed on the tips of the ear lobes. Radiographs and Steel markers will be used to construct measurement angles.

Ionising Radiation Dose

As a result of the cervical radiographs required during the research project, participants will receive a dose of ionising radiation that is not required for a medical procedure. In accordance with Human Ethics Approval, a Medical Physicist has provided an ionising radiation report. The report outlines methods, parameters and calculated doses likely to be received in this study. The conclusion from the report was “The expected dose for this research proposal is well below the dose constraints applied by the Australian Code of Practice (ACP)”.

As outlined by the ACP, the effective dose for an adult in any year is 5 mSv. The calculated dose from this project has been calculated at 0.213 mSv which is 23 times lower than the dose considered safe for an adult within a 12 month period. As part of everyday living, everyone is exposed to naturally occurring background radiation and receives a dose of about 2 mSv each year. The dose from this project is therefore 9 times less than the dose you would receive from the environment naturally within a year. At this dose level, no harmful effects of radiation have been demonstrated as any effect is too small to measure. The risk is believed to be minimal. The dose report is available for your inspection at any time.

External Cervical Photographic Measurements

Photographs will be taken from the side and front of the participants. The photographs will be used to generate three anatomic head angles which will be measured. Two angles will be generated from the side of the neck and one angle from the front of the neck. Retro reflective foam markers (attached with double sided tape) will be placed to allow the computer to construct angular measurement. The angles that are generated will allow a postural comparison between X-rays and photographs. We will conceal your identity by placing computer generated black strips over your eyes in your photos. During the third session the photographs will take 15 minutes to complete.

Standardised Stance Position

This study will utilise standardised preferred bare foot positions: the two feet will be tracked onto a sheet of paper with a marker pen while the participant stands in a comfortable position on the paper. The participant will reposition themselves on the initial tracing during the x-rays and all photographs. However, you will be asked to undergo repeated foot tracings during the second and third sessions. This will allow the researchers to determine if a foot positioning variation would have existed between trials that may affect the results.
**Flexicurve Measurement of the Thoracic Spine**

The flexicurve is a flexible plastic ruler. Once the participant is standing in a comfortable stance position the flexicurve is placed onto your spine from the base of the neck to the pelvis. When the flexicurve is removed it remains in a shape that resembles your spine. This shaped flexicurve can be used to produce an angular measure that will be compared with your neck measures. It has been shown that older chronic back pain sufferers have a greater angular measure. This project aims to investigate this curvature in healthy participants. This comparison and angle is important for the procedures that could identify at risk individuals.

**Test Description**

The biomechanical testing will occur in the Biomechanics Motion Laboratory at the University of the Sunshine Coast. We will attach using double sided tape, small 14mm retro reflective foam markers on key points located on your head, neck, trunk, upper arms and legs. These will be used to construct a 3D model that represents how you moved during the trial. Once all markers are in place we will take a series of static data recordings. We will ask you to perform a variety of static postures either unloaded (normal stance) or loaded (back pack). You will be asked to assume different standing feet positions. We will ask you to stand on two surfaces, (1) the firm surface of the force platform, and (2) a piece of 10cm thick high density foam on the force platform that will produce a soft surface which challenges the nervous system. These static postures will be performed with your eyes closed. When you perform the eyes-closed tasks, it removes all visual reference to the environment and forces your body to rely on less neural information to determine what is required to balance effectively. You may rely on your neck to help you balance - without visual information any potential variations with your neck information will become more apparent.

Please note that we will NOT be passing judgement on your ability to perform any of the required tasks. We are interested only in your postural sway parameters and these parameters are not right or wrong. We will give you all the postural cues required during data acquisition, and will demonstrate those postures for you.

**Test Duration**

You will be asked to volunteer approximately 1 hour 50 mins of their time over 3 sessions to participate in this study. The first session will be approximately 35 min in the USC Biomechanics Motion Laboratory (UBML) to undertake Preliminary Health and Orthopaedic Screening. The second session will be 15 mins at the Radiologists, located at 2/1 Scholars Drive, Sippy Downs. The third and final session will be 60 mins of postural sway data collection in the UBML. Participants are required to make their own way to the testing locations.

**Test Risks**

This test is extremely benign in nature and will not cause any discomfort. Crash mats will be placed around the force platform during all testing in case you overbalance. If you feel yourself falling during the balance trials whilst your eyes are shut, or if you experience any sensations that indicate that you are about to fall, you should open your eyes immediately. This will assist you to visually re-orientate and should prevent you from overbalancing or falling over.

However, if you are currently experiencing any shoulder, back or neck pain you will not take part in testing. Importantly, we are not going to ask you to do anything that you haven’t done many times before as part of normal everyday activity. However, please don’t hesitate to let us know if you feel uncomfortable during the testing process – remember you can withdraw from this study at any stage.
Results

Results will be used as the formal data for Lee Daffin’s PhD thesis. A summary of results will be emailed to interested participants upon completion of the study, and there will be an opportunity to attend a research presentation. Results will also be used to formulate a manuscript for submission in a peer reviewed journal.

Confidentiality

Data gathered throughout the study will be coded so that no individual participant will be identifiable (i.e. it will not be possible to find out which data belongs to any specific participant). All photographic data will be de-identified via computer generated black strips being applied over the participant’s eyes. All data collected throughout the course of this study will be kept in a locked file located at the University of the Sunshine Coast.

Complaints

Should you have any issues with any aspect of this project (e.g. testing, procedures, security of data, etc.), and you don’t feel comfortable discussing these with any of the researchers listed below you are encouraged to lodge a formal complaint through the Secretary of the University of the Sunshine Coast Human Research Ethics Committee at the Office of Research (contact 07 5459 4574 or humanethics@usc.edu.au).

Contact

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Master of Science, Candidate.
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Senior Lecturer in Sports Biomechanics
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University of the Sunshine Coast
07 5459 4703

The research team and the University would like to thank you for your interest in this project and appreciate the effort involved. The support of people like you for sports science research at the University of the Sunshine Coast is a key element contributing to our success both now and in the future.
Appendix 15: Consent to Participate in Research.

Consent to Participate in Research

Project Title

The impact of cervical lordosis on postural sway parameters in asymptomatic subjects: An evaluation and comparison between unloaded and loaded stance.

I understand that the purpose of the project is to undertake a radiological and biomechanical analysis of postural sway characteristics during unloaded and loaded quiet stance. The cervical radiological measurements and biomechanical sway findings will be compared and contrasted against the cohort’s findings. As a participant, I will be asked to undergo testing that will involve the collection of the following personal and baseline data:

Session 1:
- 3 written health questionnaires; (postural sway questionnaire, SF 36 health survey, neck disability index)
- 1 physical examination
- 1 flexicurve thoracic spine measurement
- 6 head neck postural photographs from the side view (3 images) and 3 front view.
- 1 foot tracing

Session 2:
- 2 cervical (neck) radiographs, side view and front view
- 1 flexicurve thoracic spine measurement
- 1 foot tracing

Session 3:
- 1 flexicurve thoracic spine measurement
- 9 x 90 sec postural trials, eyes closed, standing motionless
- 9 x 90 sec postural trials, eyes closed, standing motionless with a weighted back pack
- 24 head neck postural photographs from the side view (12 images) and 12 front the front.
- 4 foot tracings

Declaration:
I, ..........................................................., give my consent to participate in the project outlined above on the following basis:

I understand the contents of the Research Project Information Sheet and the Consent to Participate in Research form. I also understand that the study will be conducted as described on the Research Project Information Sheet, a copy of which I have kept.

I understand that further information concerning the study can be obtained from Lee Daffin at Lee.Daffin@research.usc.edu.au.

Signature.................................................. Date..........................

Participant
Appendix 16: The Medical Outcomes Study 36-item Short-Form Health Survey.

### SF36 Health Survey

**INSTRUCTIONS:** This set of questions asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. If you are unsure about how to answer a question please give the best answer you can.

1. In general, would you say your health is. (Please tick one box.)
   - Excellent
   - Very Good
   - Good
   - Fair
   - Poor

2. Compared to one year ago, how would you rate your health in general now? (Please tick one box.)
   - Much better than one year ago
   - Somewhat better now than one year ago
   - About the same as one year ago
   - Somewhat worse now than one year ago
   - Much worse now than one year ago

3. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much? (Please circle one number on each line.)

<table>
<thead>
<tr>
<th>Activities</th>
<th>Yes, Limited A Lot</th>
<th>Yes, Limited A Little</th>
<th>Not Limited At All</th>
</tr>
</thead>
<tbody>
<tr>
<td>3(a) 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>3(b) 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>3(c) Lifting or carrying groceries</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3(d) Climbing several flights of stairs</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3(e) Climbing one flight of stairs</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3(f) Bending, kneeling, or stooping</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3(g) Walking more than a mile</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3(h) Walking several blocks</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3(i) Walking one block</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3(j) Bathing or dressing yourself</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

4. 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? (Please circle one number on each line.)

<table>
<thead>
<tr>
<th>Problems</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>4(a) Cut down on the amount of time you spent on work or other activities</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4(b) Accomplished less than you would like</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4(c) Were limited in the kind of work or other activities</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4(d) Had difficulty performing the work or other activities (for example, it took extra effort)</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

5. 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 (e.g. feeling depressed or anxious)? (Please circle one number on each line.)

<table>
<thead>
<tr>
<th>Problems</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>5(a) Cut down on the amount of time you spent on work or other activities</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5(b) Accomplished less than you would like</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5(c) Didn’t do work or other activities as carefully as usual</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
6. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbours, or groups? (Please tick one box.)
   - Not at all
   - Slightly
   - Moderately
   - Quite a bit
   - Extremely

7. How much physical pain have you had during the past 4 weeks? (Please tick one box.)
   - None
   - Very mild
   - Mild
   - Moderate
   - Severe
   - Very Severe

8. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)? (Please tick one box.)
   - Not at all
   - A little bit
   - Moderately
   - Quite a bit
   - Extremely

9. These questions are about how you feel and how things have been with you during the past 4 weeks. Please give the one answer that is closest to the way you have been feeling for each item.

   (Please circle one number on each line.)

<table>
<thead>
<tr>
<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>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

   9(a) Did you feel full of life?  
   9(b) Have you been a very nervous person?  
   9(c) Have you felt so down in the dumps that nothing could cheer you up?  
   9(d) Have you felt calm and peaceful?  
   9(e) Did you have a lot of energy?  
   9(f) Have you felt downhearted and blue?  
   9(g) Did you feel worn out?  
   9(h) Have you been a happy person?  
   9(i) Did you feel tired?  

10. 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.) (Please tick one box.)

   - All of the time
   - Most of the time
   - Some of the time
   - A little of the time
   - None of the time

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

   (Please circle one number on each line.)

<table>
<thead>
<tr>
<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>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

11(a) I seem to get sick a little easier than other people.  
11(b) I am as healthy as anybody I know.  
11(c) I expect my health to get worse.  
11(d) My health is excellent.
Appendix 1: Neck Disability Index

Section 6: Concentration

☐ I cannot concentrate at all
☐ I have a great deal of difficulty in concentrating when I want to
☐ I have a little difficulty in concentrating when I want to
☐ I have no difficulty in concentrating when I want to

Section 5: Headaches

☐ I cannot read at all
☐ I have a great deal of difficulty reading in my neck
☐ I have a little difficulty reading in my neck
☐ I have no difficulty reading in my neck

Section 4: Reading

☐ I cannot do any writing

Section 3: Lighting

☐ I do not get dressed
☐ I read in bed
☐ I can do household chores
☐ I can help with children
☐ I can help with cooking
☐ I can help with the house cleaning

Section 2: Personal Care (Washing, Dressing, etc.)

☐ I cannot do personal care
☐ I need help
☐ I can do personal care

Section 1: Pain Intensity

Please indicate the intensity of your pain by checking the box that most closely describes your problem.

Box that applies to you. We cannot provide you with a numerical score for the pain scale. However, your physician may choose to use a numerical score to help. Please indicate in each section only one score. The questionnaire can be completed in your information so you can have a record of your pain for future reference.
Section 1: Reception

- I can’t do any reception activities at all.
- I can’t do any reception activities because of pain in my neck.
- I can’t do any reception activities because of pain in my neck.
- I can’t do any reception activities because of pain in my neck.
- I can’t do any reception activities because of pain in my neck.
- I can’t do any reception activities because of pain in my neck.
- I can’t do any reception activities because of pain in my neck.

Section 2: Driving

- I can’t do any driving at all.
- I can’t drive because of pain in my neck.
- I can’t drive because of pain in my neck.
- I can’t drive because of pain in my neck.
- I can’t drive because of pain in my neck.

Section 3: Sleeping

- I can’t do any sleeping activities at all.
- I can’t do any sleeping activities because of pain in my neck.
- I can’t do any sleeping activities because of pain in my neck.
- I can’t do any sleeping activities because of pain in my neck.
- I can’t do any sleeping activities because of pain in my neck.

Section 4: Work
Appendix 18: Postural Sway Questionnaire.

POSTURAL SWAY QUESTIONNAIRE

All questions contained in this questionnaire are strictly confidential and will become part of your research record.

<table>
<thead>
<tr>
<th>Names</th>
<th>☐ N ☐ F □ DOB:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address:</td>
<td></td>
</tr>
<tr>
<td>Phone: ☐ (H) ☐ (M)</td>
<td>E-mail Address:</td>
</tr>
</tbody>
</table>

PERSONAL HEALTH HISTORY

Are you healthy and have never suffered from chronic cervical spine problem and are without neck pain presently? ☐ Y ☐ N

<table>
<thead>
<tr>
<th>Neck History Information</th>
<th>Do you have full and painless neck range of motion (ROM) with no signs of tenderness in the shoulder or cervical muscles? ☐ Y ☐ N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Do you have a history of motor vehicle accident whiplash or physical neck trauma? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Do you suffer from chronic headaches that are more pronounced than neck pain, tension type or Migraine? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Do you suffer from severe pain in any body parts other than the neck? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Have you over the last year experienced any periods of dizziness, unsteadiness or vertigo without any episodes of severe neck pain prior to dizziness, unsteadiness or vertigo events? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Are you able to turn your head to 45° either side without pain in your neck or shoulder? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Do you suffer from chronic lower back pain? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Do you have impaired function (pathology) of the lower limbs, hip, knee, foot, recurrent ankle sprain / strains? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Have you ever been diagnosed with signs of cervical (neck) osteoarthritis following radiological examination? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Do you have any degenerative arthritis within any joints in your body that required active management? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Do you suffer from a history of repetitive falls, as a result of dizziness or unsteadiness? ☐ Y ☐ N</td>
</tr>
<tr>
<td></td>
<td>Do you suffer from scoliosis or any congenital anomalies of the spine? ☐ Y ☐ N</td>
</tr>
</tbody>
</table>

Have you fractured or suffered joint dislocations?

<table>
<thead>
<tr>
<th>Year</th>
<th>Bone / Joint</th>
<th>Functional Impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Do you have or have ever had Spondylolisthesis ☐ Schauermann’s disease ☐ A Spinal Tumor ☐ An infection of the dural sac ☐

Inflammatory Arthritis Diseases Arthritis ☐ Psoriatic arthritis ☐ Rheumatoid arthritis ☐

Metabolic Diseases Osteoporosis ☐ Diabetic disease ☐ Pseudogout ☐

Previous Respiratory Illness Asthma ☐ Bronchitis ☐ Recurrent acute infection of the upper airways ☐

Have you ever had either Major or Minor Surgery? ☐ Y ☐ N

Surgical fixation of a joint to promote bone fusion particularly in the neck, foot or ankle? ☐ Y ☐ N

Recent Orthopaedic Surgery? ☐ Y ☐ N

Hospitalizations and Surgeries

<table>
<thead>
<tr>
<th>Year</th>
<th>Reason</th>
<th>Hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Have you ever had a blood transfusion? ☐ Yes ☐ No

Please turn to next page.
### List any medical pathology that any doctor or specialist has diagnosed?

- Neurological disease
- Brain damage
- Vestibular pathology
- Vision disorders not corrected by glasses
- Hearing or inner ear pathology
- Rheumatic diseases
- Psychiatric conditions
- Auto Immune Diseases
- Abnormal blood pressure
- Type 1 or 2 diabetes
- Posttraumatic amnesia
- Muscular disorders
- Concurrent head injury
- Unconsciousness
- Balance pathology
- Meniere’s disease
- Others:

  - Do you consume any pharmaceutical drugs affecting the nervous system or that have side effects resulting in sensorimotor dysfunctions, postural control or produce vertigo? □ Y □ N
  - Do you take more than four pharmaceutical medications on a daily basis? □ Y □ N

### List your prescribed drugs and over the counter drugs, such as vitamins and inhalers

<table>
<thead>
<tr>
<th>Name of the Drug</th>
<th>Strength</th>
<th>Frequency Taken</th>
<th>Side Effects Experienced</th>
</tr>
</thead>
</table>

### Allergies to Medications

- Name of Drug
- Reaction you had to the drug

### Health Habits and Personal Safety Information

All sensitive information will be kept strictly confidential. Only one investigator will have access to it.

#### Exercise
- □ Sedentary (No exercise)
- □ Mild exercise (i.e., climb stairs, walk 3 blocks, golf)
- □ Occasional vigorous exercise (i.e., work or recreation, less than 4x/week for 30 min)
- □ Regular vigorous exercise (i.e., work or recreation 4x/week for 30 minutes)

#### Daily Posture

<table>
<thead>
<tr>
<th>Sitting at a Computer</th>
<th>1 to 2 hours per day</th>
<th>3 to 4 hours day</th>
<th>More than 4 hours day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional Sitting Time</td>
<td>1 to 2 hours per day</td>
<td>3 to 4 hours day</td>
<td>More than 4 hours day</td>
</tr>
</tbody>
</table>

#### Caffeine

- □ None
- □ Coffee
- □ Tea
- □ Cola

<table>
<thead>
<tr>
<th># of cups/cans _______ per day</th>
</tr>
</thead>
</table>

#### General Health

- Have you ever been exposed to toxic substances? □ Yes □ No
- Do you need walking / standing aid such as a cane? □ Yes □ No
- Are you pregnant or breast feeding? □ Yes □ No
- Do you have a history of chronic alcohol or drug consumption / abuse? □ Yes □ No

#### Alcohol

- Do you drink alcohol? □ Yes □ No

#### Tobacco

- Do you use tobacco? □ Yes □ No

#### Pre-Data Collection

- Can you inform the researcher if you had or undertaken the following 1 week prior to the investigation? □ Yes □ No

  - *Pain management, e.g. any medication in the 24 h prior to testing. An acute musculoskeletal injuries or treatment for that injury.*
  - *Physical injuries or events identical to the listed events above.*

---

**Thank you for completing this questionnaire**
Appendix 19: Postural Sway Questionnaire Information Sheet.

POSTURAL SWAY QUESTIONNAIRE INFORMATION SHEET

If you have any difficulties understanding a question or questions please ask the research investigator for help.

Please Note: If you are unsure about a particular medical condition you more than likely do not have the condition.

Here are some general definitions of the medical terms listed (in order as found in the questionnaire):

- **Dizziness, Unsteadiness or Vertigo;** An inability to coordinate and maintain balance.
- **Pathology;** The effects of a disease.
- **Osteoarthritis;** A bone condition in which there is degenerative changes present within the skeletal joint structure.
- **Scoliosis;** Lateral curvature of the spine in the front view.
- **Congenital Abnormalities;** Present at birth, characteristic considered not normal.
- **Spondylolisthesis;** A forward dislocation of one vertebrae over the one below, the most common segment involved is L5/S1.
- **Scheuermann’s disease;** Spinal condition characterised by fixed thoracic kyphosis with wedged shaped vertebrae and intervertebral disc protrusion through the vertebral end plate.
- **Ankylosing Spondylitis;** A Chronic inflammatory disease in which the spine undergoes progressive fusion of the vertebrae, other joints are affected later.
- **Reiter Syndrome;** A male arthritic condition believed to be bacterial in origin that affects feet, sacroiliac joints, eyes and urinary system.
- **Psoriatic Arthritis;** An arthritic condition associated with psoriatic skin lesions affecting joints primarily in the hand and feet.
- **Rheumatoid Arthritis;** A chronic auto immune disease of collagen structures within the joints. It symmetrically deforms skeletal joints resulting in fusion at the end stage.
- **Osteoporosis;** An abnormal bone condition resulting in bone demineralisation it has may causative factors.
- **Paget disease;** A disease characterised by excessive bone destruction and unorganised bone repair.
- **Osteomalacia;** An abnormal bone condition characterised by a loss of calcification.
- **Vestibular pathology;** Disease within the inner ear structure resulting in impaired balance.
- **Meniere’s disease;** A chronic inner ear disease characterised by vertigo and hearing loss and excessive tinnitus.
- **Rheumatic disease;** An inflammatory condition of various tissues within the body including arteries, heart, brain, joints, skin and subcutaneous tissues.
- **Posttraumatic amnesia;** A loss of memory as a result of trauma to the head.
Appendix 20: The Neuromusculoskeletal Physical Examination:

University of the Sunshine Coast
Queensland, Australia

PHYSICAL EXAMINATION

All results contained in this examination are strictly confidential and will become part of your research record.

<table>
<thead>
<tr>
<th>Subject Identification Code:</th>
<th>Postural Sway Number</th>
<th>PS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height:</td>
<td>cm</td>
<td></td>
</tr>
<tr>
<td>Weight:</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Foot Length:</td>
<td>cm</td>
<td></td>
</tr>
</tbody>
</table>

| Blood Pressure (R)           | (L)                  |
| Standing Postural Photographe x3: (L) Lateral | AP |

ORTHopaedic and Neurological Examination

Aden's Iliopsoas Scoliosis Test: +ve ○ -ve ○ Comment:
Peripheral Joint Screen Full Squat Test: +ve ○ -ve ○ Comments
Modified Romberg’s Eyes Open: +ve ○ -ve ○ Eyes Closed (EC): +ve ○ -ve ○ Comments
Side of Coronal Head Tilt: Right ○ Left ○ Side of Sway Romberg’s EC: Right ○ Left ○
Cerebellar Finger to Nose Test 3 repetitions: Right Arm ○ Left Arm ○ Comment:

SHOULDER Active RANGE OF MOTION STANDING

<table>
<thead>
<tr>
<th>(R)</th>
<th>Flexion (165 or &gt;)</th>
<th>(L)</th>
<th>Extension (90 or &gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R)</td>
<td>Abduction (160 or &gt;)</td>
<td>(L)</td>
<td>Adduction (75 or &gt;)</td>
</tr>
<tr>
<td>(R)</td>
<td>Abd Lat Rot (65 or &gt;)</td>
<td>(L)</td>
<td>Abd Ext Rot (90 or &gt;)</td>
</tr>
</tbody>
</table>

ACTIVE CERVICAL RANGE OF MOTION SITTING

<table>
<thead>
<tr>
<th>Flexion (60 or &gt;)</th>
<th>Extension (75 or &gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Lateral Flexion (45 or &gt;)</td>
<td>Left Lateral Flexion (45 or &gt;)</td>
</tr>
<tr>
<td>Right Rotation (80 or &gt;)</td>
<td>Left Rotation (80 or &gt;)</td>
</tr>
</tbody>
</table>

PASSIVE CERVICAL RANGE OF MOTION SITTING

<table>
<thead>
<tr>
<th>Flexion (60 or &gt;)</th>
<th>Extension (75 or &gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Lateral Flexion (45 or &gt;)</td>
<td>Left Lateral Flexion (45 or &gt;)</td>
</tr>
<tr>
<td>Right Rotation (80 or &gt;)</td>
<td>Left Rotation (80 or &gt;)</td>
</tr>
</tbody>
</table>

RESISTED NEUTRAL CERVICAL ISOMETRIC MUSCLE TESTING

<table>
<thead>
<tr>
<th>Flexion</th>
<th>Normal ○ Pain ○ Weakness ○</th>
<th>Extension</th>
<th>Normal ○ Pain ○ Weakness ○</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Lateral Flexion</td>
<td>Normal ○ Pain ○ Weakness ○</td>
<td>Left Lateral Flexion</td>
<td>Normal ○ Pain ○ Weakness ○</td>
</tr>
<tr>
<td>Right Rotation</td>
<td>Normal ○ Pain ○ Weakness ○</td>
<td>Left Rotation</td>
<td>Normal ○ Pain ○ Weakness ○</td>
</tr>
</tbody>
</table>

INTERVERTEBRAL DISC AND INTERVERTEBRAL FORAMEN TESTING

Valsalva’s Maneuver (Space Occupying Lesion): +ve ○ -ve ○ Comment:
Seated Neutral Distraction: +ve ○ -ve ○ Seated Neutral Compression: +ve ○ -ve ○
Seated Flexion Compression: +ve ○ -ve ○ Seated Extension Compression: +ve ○ -ve ○
(L) Seated Maximal Foraminal Compression Test (R)

NOTES:

Self-Balance Procedure Explanation Sheet

The self-balance procedure is very important for postural positioning during this study. Its goal is to help standardise your relaxed natural head, upper limb and trunk posture.

A natural head posture is achieved by performing large range of motion movements of the head and neck with your eyes closed. The head is move as far as possible tilting it forward as if looking towards the ground. Then as far back as possible as if looking towards the sky. All movements neck movements you perform should be controlled and pain free.

Gradually the amount of movements in both directions is decreased. This reduction in head and neck motion continues until a stationary comfortable balanced head position is achieved. When this is achieved, please open your eyes. Realistically this should be no more than 5 repetitions until you reach a stationary position.

As your head comes to rest allow your shoulders to relax and adopt a natural posture with both arms allowed to hang free and comfortable by the side of your trunk. Once this comfortable relaxed position is achieved can you relax your jaw the allowing your teeth to be held together lightly in their typical resting position. Do not clench your teeth.

At this point you should be standing as relaxed and as comfortable as you can, in a position that you consider to be your natural standing position. Your head should be resting on your neck in a position that allows your eyes to be looking straight ahead.

The goal of this study is to investigate balance control while you are standing in your natural posture. Could you please not adopt a posture that you thing the researcher is looking for. The project is investigating balance control which is inherent and individual to your nervous system. We are not investigating full body posture or alignment.

Relax; stand as comfortable and still as possible.