School of Physiotherapy and Exercise Science

An investigation of neck posture clusters; their relationship to neck pain and biopsychosocial factors

Karen Victoria Richards

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Human Ethics (For projects involving human participants/tissue, etc) The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number HR84/205 and HR67/2013.

Signature:

Date: 2nd December 2016

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Abstract

Background

There is conflicting evidence on the relationship between sagittal neck posture and neck pain. Most evidence is cross sectional in nature, and based on weakly characterised posture and lacks consideration of biopsychosocial factors known to be associated to both neck pain and posture. Longitudinal studies investigating neck posture as a risk factor for neck pain are scant, display similar limitations and have not demonstrated evidence of a link.

Purpose

There were 3 aims: (i) to determine the existence of neck posture clusters in 17-year-old adolescents; (ii) to establish whether identified clusters were associated with biopsychosocial factors, persistent neck pain, neck pain made worse in sitting and headaches; (iii) using a longitudinal design to determine whether neck posture clusters at 17 were a risk factor for neck pain in young adults independent of other related factors.

Methods

One thousand one hundred and eight 17-year-olds enrolled in the Western Australian Pregnancy Cohort (Raine) Study underwent photographic postural assessment in sitting. One distance and four angular measures of the head, neck and thorax were calculated from photo-reflective markers placed on bony landmarks. Subgroups of sagittal sitting neck posture were determined by cluster analysis. Height and weight were measured and lifestyle and psychological factors, as well as neck pain and headache, were assessed by questionnaire. The associations between posture clusters, neck pain, headaches and other factors at 17 years were evaluated using logistic regression.

At the age of 22, 686 participants with both postural measures and neck pain data from the 17 years follow up completed a questionnaire about neck pain and workplace demands. The relationship between neck posture clusters and persistent neck pain at 22 were explored using logistic regression accounting for other related factors. An interaction test between posture cluster membership and workplace demands was performed.

Results

Clusters: Four distinct clusters of sitting neck posture were identified and characterised as upright, intermediate, slumped thorax/forward head and erect thorax/forward head postures.

Associative factors: Significant associations between cluster and sex, weight and height, were found. Adolescents classified as having slumped thorax forward/head posture were at higher odds of mild, moderate or severe depression. Adolescents classified as having upright posture exercised more frequently. There was no significant difference in the odds of persistent neck pain, neck pain made worse by sitting or headache across the clusters. Female sex was strongly associated with neck pain.

Risk factors: Sitting neck posture at 17 was not found to be predictive of persistent neck pain at 22. However persistent neck pain at 17 and being female were. The prevalence of neck pain did not vary across occupational groups classified by physical demands among the four posture clusters at 22

Conclusion

Sagittal sitting neck posture clusters were identified in 17-year-olds that align with common clinical perceptions. Clusters differed on biopsychosocial profiles. The finding of no association between cluster membership and neck pain in both the cross sectional and longitudinal analysis challenges widely held beliefs about the role of posture in adolescent neck pain.

Implications

The premise for the clinical assessment of posture should be reconsidered and take into account other factors, such as sex, height, weight, exercise frequency and depression. The results question the practice of population based and individual advice to “sit up straight” for the prevention of neck pain.

Publications and conference presentations

RICHARDS, K. V., BEALES, D. B., SMITH, A. J., O'SULLIVAN, P. B. & STRAKER, L. M. 2016. Neck posture clusters and their association with biopsychosocial factors and neck pain in Australian adolesents. *Physical Therapy,* 96**,** 1576-1587.

RICHARDS, K. V., BEALES, D. B., SMITH, A. J., O'SULLIVAN, P. B. & STRAKER, L. M. 2016. Well characterised neck posture is not related to neck pain in adolescents in a large community-based sample. *IFOMPT, Glasgow*

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(Awarded Raine Study Medical Research Foundation prize for the best presentation by a new researcher)

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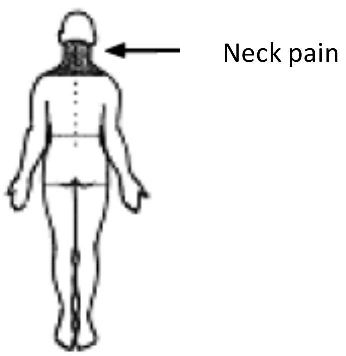
List of abbreviations

BDI-Y	Beck Depression Inventory for Youth
BMI	body mass index
CI	confidence interval
EMG	electromyography
IQR	interquartile range
NP	neck pain
NPQ	Northwick Park neck pain questionnaire
OR	odds ratio
PNP	persistent neck pain
RCT	randomised controlled trial
RR	risk ratio
SF-36	Short form 36 item questionnaire

Chapter 1 - Literature Review

The purpose of this literature review was to investigate the relationship between neck posture and neck pain. In this thesis neck pain is defined as pain felt dorsally between the inferior margin of the occiput and the superior margin of T1 that may spread into the upper trapezius area (Figure 1.1). MEDLINE (Pub med)/ EMBASE/ Ovid, Web of Knowledge, Science Direct, CINAHL and Cochrane electronic data bases were searched. The following the key search terms were used in various combinations; neck posture, head posture, sagittal posture, alignment, neck pain, biopsychosocial factors, psychosocial factors, psychological factors, sedentary, computer use, muscle performance. Articles about posture were excluded if they did not include sagittal measures posture at the head, neck or thorax. There was no limit based on publication status or study date, however an English language restriction was used. Reference lists of key articles were searched (snowballing) and postural or neck pain and relevant psychosocial factors studies were obtained.

Figure 1.1: *Area of neck pain used in this thesis*



A brief review of the epidemiology of neck pain is followed by a short review of the multidimensional nature of neck pain. The focus then shifts to a detailed review of neck posture as one of these factors. Firstly potential mechanistic links between neck posture and neck pain will be discussed. This is followed by a review of the methodologies of assessing neck posture. Then the concept of ideal neck posture is discussed, and the potential for postural sub-groups. The focus then returns to factors known to influence neck posture, which as per neck pain are multidimensional in nature. The following section then thoroughly reviews the role of neck posture as both being associated with and a risk factor for neck pain. Limitations in this literature are discussed prior to setting out the premise for this thesis in light of the findings from this review of the literature.

1.1. Epidemiology

1.1.1 The burden of neck pain:

Neck pain (NP) is a common complaint in adult and adolescent populations (Fejer et al., 2006b, Straker et al., 2009, Global Burden of Disease Study, 2015, Vos et al., 2012) and is a substantial public health concern. The International Task Force on Neck Pain suggested that most people can expect to experience some NP in their lifetime (Haldeman et al., 2008). Symptoms often have a gradual onset and undertake an episodic course over a person's lifetime (Cote et al., 2009, Hoy et al., 2010b). It has been reported that NP in the Netherlands has had major economic consequences through the cost of healthcare, work absenteeism and social welfare sickness benefits (Borghouts et al., 1999). Australian figures have shown that NP accounts for 20% of all chronic pain (Blyth et al., 2001), but there are no true Australian cost estimates.

There is evidence of an increasing trend of NP in adolescents, with the prevalence of NP being higher in 1999 - 2001 compared to 1991 in a 12-18 year old age group (Hakala et al., 2002). In 1991 NP affected 7% of girls and 5% of boys aged 12, 15% of girls and 7% of boys aged 14, 24% of girls and 9% of boys aged 16 and 36% in girls and 14% in boys aged 18 whereas in 2001 NP affected 15% of girls and 6% of boys aged 12, 24% of girls and 12% of boys aged 14, 45% of girls and 19% of boys aged 16 and 45% of girls and 19% of boys aged 18 (Hakala et al., 2002). A recent global burden of disease study found NP prevalence had increased worldwide by 54.1% between 1990 and 2013 (Global Burden of Disease Study, 2015). The rising prevalence is also evident in rising economic costs. Between 2000 and 2010 treatment costs and the percentage of healthcare resources spent on NP rapidly increased throughout the world (Haldeman et al., 2008), a trend likely to be occurring in Australia.

1.1.2 Neck pain in adolescence:

It has been proposed that NP originates in childhood (Brattberg, 2004). Studies illustrate a rising prevalence of NP throughout adolescence (Hakala et al., 2002, Niemi et al., 1996, Vikat et al., 2000, Jeffries et al., 2007), with 12-month estimates ranging between 21-42% in this age group (Hogg-Johnson et al., 2009). Neck pain prevalence levels in adults have been reported to range between 30-50% in the majority of studies (Hogg-Johnson et al., 2009), with a peak incidence of NP between the ages of 30-45 (Croft et al., 2001). Symptoms of NP in adolescence have also been shown to be a risk factor for NP in adults in their mid to late 20s (Hertzberg, 1985).

The epidemiological evidence suggest that there are many cases of mild NP (Hogg-Johnson et al., 2009). About one third of people experience a complete resolution of symptoms following an episode of NP (Cote et al., 2004). Relapses are common, with most cases of NP running an episodic course over a person's lifetime (Hoy et al., 2010b). A previous review found that between 50-85% of people who experience an episode of NP continued to report symptoms 1-5 years later (Carroll et al., 2008). Consistent with this, NP ranks highly for the number of years lived with disability in the world, placed second in high-income countries, ranked third in Australia and fourth in the world (Vos et al., 2012, Global Burden of Disease Study, 2015). The 1 year prevalence of NP that was significant enough to interfere with schoolwork or leisure activities has been reported as 14% in boys and 23% in girls aged between 10 -17 years (Kujala et al., 1999). In adults, NP that limits activity has been reported as less common, with 12 month prevalence rates ranging from 2%-11% (Hogg-Johnson et al., 2009) although the reason for this is unclear but may be related to the definition of NP "interference". Less than 1% (0.6%) of the population are reported to experience disabling NP (Cote et al., 2004).

In summary NP is common. Evidence suggests that NP develops in adolescence with a substantial increase in prevalence throughout the teenage years. In order to curb the growing disability and costs associated with NP, a better understanding of the underlying mechanisms for NP is required to enable informed prevention and management strategies.

1.1.3 Relationship between neck pain and headaches:

Axial NP commonly refers into the upper trapezius area (Bogduk and Govind, 2009b) and is frequently described as neck shoulder pain. Pain from the upper cervical spine can also refer pain into the head as a result of convergence of the trigeminal afferents and afferents from C1 -3 spinal nerves into the trigeminocervical nucleus; this type of secondary headache is termed a cervicogenic headache (Bogduk, 2001, Bogduk and Govind, 2009b). In turn primary headache symptoms from migraine or tension type headache can refer pain into the neck. Criteria from the cervicogenic headache study group can enable differentiation of headache type with some overlap, however the subgroups of headache may co-exist (Vincent, 2010). A lack of biomarkers can make differentiation difficult (Vincent, 2010). In particular, cervicogenic and tension type headaches are not differentiated well in the research literature. Headaches are common. Tension type headaches and migraines are two of the most prevalent conditions in the world ranking 2nd and 7th respectively, and individually they affected over 10% of the world population in 2013 (Global Burden of Disease Study, 2015). In addition, the burden of migraine currently ranks sixth for the numbers of years lived with disability (Global Burden of Disease Study, 2015). It has been estimated that 14-18% of chronic headaches are cervicogenic (Zito et al., 2006).

In summary, NP and cervicogenic, tension type and migraine headaches are physiologically related to NP through the trigemiocervical nucleus. Headaches are amongst the world's most common conditions and create significant impact on individuals.

1.2 Multidimensional factors associated with and risk factors for neck pain

Multiple factors are related to NP; some of these are associative factors, based on results of cross-sectional studies, while others are risk factors based on results of longitudinal studies. These factors can broadly be grouped into genetic, anthropometric, lifestyle, psychological, co-morbid factors and physical factors. Table 1.1 highlights similarities between associated factors and risk factors in adolescent and adult populations.

1.2.1 Sex:

Females consistently demonstrate a greater prevalence of NP in adolescent and adult groups, with evidence from systematic reviews (Cote et al., 2009, Fejer et al., 2006b), large population based cohorts (Cote et al., 2004, Hakala et al., 2002) and large cross-sectional studies (Vikat et al., 2000, Walker-Bone et al., 2004). This finding is consistent with other musculoskeletal pain disorders including low back pain (Hoy et al., 2010a) and headaches (Stovner et al., 2006). The potential reasons for sex differences in report of pain disorders are complex and have been presented in detail elsewhere (Hashmi and Davis, 2014).

1.2.2 Genetics:

There are few studies of the heritability of NP, but two large twin studies support the presence of a heritable component (Fejer et al., 2006b, Stahl et al., 2013). A large twin study investigating the heritability of NP in early adolescence, found stronger associations between NP experienced at least once a week over the previous 3 months in monozygotic twins compared to dizygotic twins. Model fitting apportioned 68% of the variation in NP as genetic, suggesting a strong genetic influence, with other environmental factors making up the remainder (Stahl et al., 2013). The influence of genetics in NP may decrease with age, with increased significance of environmental factors in older age groups (Fejer et al., 2006a).

Table 1.1: *Identified associative and risk factors for neck pain in adolescent and adult populations*

Factors	In Adolescents	In Adults
Age	• Increasing age (Vikat et al., 2000, Hakala et al., 2002, Niemi et al., 1996, Grimmer et al., 2006, Jeffries et al., 2007)	• **Peak incidence between 30 – 45 years (Croft et al., 2001)**
Sex	• Female sex (Hakala et al., 2002, Vikat et al., 2000)	• **Female sex** (Walker-Bone et al., 2004, Cote et al., 2004, **Siivola et al., 2004**)
Genetic	• Genetics accounts for 68% liability to NP (Stahl et al., 2013)	• Less genetic influence with increased age (Fejer et al., 2006a)
Lifestyle factors	• Computer use (Smith et al., 2008b, Myrtveit et al., 2014) • “A lot” or “not at all” panting when partaking in physical exercise versus moderate levels of exercise (Vikat et al., 2000) • Smoking status (Vikat et al., 2000)	• **Duration of sitting (Ariens et al., 2001a)** • Smoking history (Walker-Bone et al., 2004)
Psychological factors	• Depressive symptoms and stress (Niemi et al., 1996, Diepenmaat et al., 2006, Pollock et al., 2011, Rees et al., 2011) • **Lower mental health score (Ehrmann Feldman et al., 2002)** • Psychosomatic stress (Siivola et al., 2004)	• **Poor mental health and psychological distress** (Walker-Bone et al., 2004, **Croft et al., 2001**) • **Psychosomatic stress (Siivola et al., 2004)**
Occupational factors	• **Work status (Ehrmann Feldman et al., 2002)** • Poor school achievement (Vikat et al., 2000)	• Military specific, arts, design entertainment, sports and media, health care support, installation maintenance and repair occupations (Yang et al., 2015) • **High qualitative job demands and low co-worker support (Ariens et al., 2001b)** • Greater hours of employment (Yang et al., 2015)
Co-morbid factors	• Frequent colds and Long term illness (Vikat et al., 2000) • Lower back pain (Vikat et al., 2000) • Co-existence of other musculoskeletal disorders (Vikat et al., 2000)	• **Ill health (Croft et al., 2001)** • **Lower back pain (Croft et al., 2001)** • Pain at multiple sites (Walker-Bone et al., 2004) • **Previous history of neck injury (Croft et al., 2001)** • **Previous history of pain elsewhere (Croft et al., 2001)**
Other factors	• Wearing glasses / contact lenses (Vikat et al., 2000) • Earlier onset of puberty (Vikat et al., 2000)	
Anthropometric measures		• **Shorter stature at age 11** and 22 **(Poussa et al., 2005)** • **Increased body mass index (Luime et al., 2004)**
Physical factors	• Posture (Oliveira and Silva, 2016, Ruivo et al., 2014)	• Neck muscle performance (Lee et al., 2005, Cagnie et al., 2007, Falla et al., 2004, Jull et al., 2004, O'Leary et al., 2011a, O'Leary et al., 2011b, O'Leary et al., 2007) • Posture (Yip et al., 2008, Osmotherly and Attia, 2008, Harrison et al., 2004, Silva et al., 2009, Lau et al., 2010)

Bold type denotes prospective design studies

1.2.3 Lifestyle factors

Computer use: There are mixed reports regarding the association of computer use and NP. Most studies are cross sectional in nature, and have been conducted in large adolescent cohorts. An association was reported between frequent screen based activities and frequent NP experienced in the last 6 months in an adolescent population based study in Norway (Myrtveit et al., 2014). However, screen based activities were sub classified and not all subgroups of computer use were associated with NP. After adjustment for depression, boys using the computer for greater than two hours a day of emailing (odds ratio (OR) 1.95, 95% confidence interval (95% CI) 1.30 – 2.92) and boys and girls playing computer games remained associated with NP (OR 1.31, 95% CI 1.06 – 1.64 and OR 1.62 95% CI 1.22 – 2.13). Higher levels (>8.5 hours per week) of computer use were found to be associated with NP experienced in the last month in South African high school students (OR 1.7 95% CI 1.2 – 2.3) (Smith et al., 2008b). However the presence of NP was multiplied by the severity of NP (slight discomfort or a lot of discomfort) to create a score, which potentially skewed results. Conversely another large adolescent cohort study in the Netherlands found that computer use was not associated with NP experienced for greater than four days in the last month (overall odds ratios not reported) (Diepenmaat et al., 2006). The different definition of NP may account for the different results of the Dutch study to the Norwegian and South African studies. Furthermore different definitions of computer use were used by each study, which may also explain their different findings. Unlike the Norwegian study, different types of computer use such as chatting online and playing computer games were combined in the South African study and may account for the difference in outcome. Similarly, the amount of time using the computer was not found to be associated with NP in the last month or chronic NP in a cohort of Australian 14 year old adolescents (Briggs et al., 2009). It has been hypothesised that the mechanism for an association between computer use and NP may be related to the alteration of posture required to operate a keyboard and screen based activities (Straker et al., 2007). However, due the equivocal findings in the literature the link between computer use and NP remains unclear.

Exercise: The evidence of the effect of physical exercise on NP is disputed. Varying definitions of exercise has made comparison between studies challenging. In a Finnish longitudinal cohort study, as compared to hobbies that involved static loading of the upper limbs, participation in upper limb dominated sports as an adolescent was associated with a lower prevalence and decreased the risk of frequent NP 7 years later (risk ratio (RR) 0.4, 95% CI 0.2 - 0.8) (Siivola et al., 2004). However, in the same study moderate intensity physical activity in adolescence (defined by somewhat panting when exercising) increased the risk of NP 7 years later (RR 1.9, 95% CI 1.0 – 3.4). While speculative, potentially sports that dynamically load the upper limbs may improve the strength of the shoulder/neck musculature and interact with NP in a way that static exercise does not. Adults in the Netherlands that participated in sporting activities for at least 10 months a year had a small decreased risk of NP as compared to those who participated in sporting activities less than 3 months of the year (OR 0.82, 95% CI 0.67 - 0.99) (van den Heuvel et al., 2005). However the same study found that the number of hours participating in sporting activities per week was not associated with NP (van den Heuvel et al., 2005). When compared to practising sport less than 1 hour per week, there was no difference in the odds of NP when practising sport 1-3 hours per week (OR 0.93, 95% CI 0.75 – 1.14) or more than three hours per week (OR 0.93, 95% CI 0.75 – 1.15). Potentially continuance of sports participation is a greater contributor to decreasing NP than the amount of sport per week in adults. However, another prospective adolescent study found the risk of development of NP over a 12 month period to be similar in those who took part in sporting activities and those who did not even after exploring sports participation in three ways; firstly by classifying sports by the sum of metabolic activity per week (OR 1.00, 95% CI 0.99 – 1.01); secondly by different categories of sports (e.g. swimming sports (OR 1.04, 95% CI 0.99 – 1.08), racquet sports (OR 0.98, 95% CI 0.93 – 1.02), throwing sports (OR 1.01, 95% CI 0.99, 1.04), collision sports (OR 0.99, 95% CI 0.97 – 1.02)) and thirdly by dichotomising sports participation (e.g. participating in sport or not (OR 1.00, 95% CI .98 – 1.01) (Ehrmann Feldman et al., 2002). In line with this, a Dutch cross sectional study found no difference in the prevalence of NP in adolescents who exercised at a metabolic rate greater than 5 kilojoules per hour, when those who exercised less than 30 minutes per day were compared to those who exercised more than 30 minutes per day (OR 0.8, 95% CI 0.6 – 1.1) or to those who exercised more than 1 hour per day (OR 0.8, 95% CI 0.6 – 1.0) (Diepenmaat et al., 2006). However a metabolic rate of 5 appears to be a low level of exercise and activities such as running, cycling and swimming have a metabolic rate of 21 – 33.6 kilojoules per hour in children (Diepenmaat et al., 2006). Conversely a Finnish cross sectional study found adolescents that reported either "a lot" (OR 1.2, 95% CI not reported) or "not at all" (OR 1.2, 95% CI not reported) panting when exercising were more likely to experience weekly NP than those who exercised to a moderate intensity suggesting both high and low levels of aerobic exercise may be a risk for NP (Vikat et al., 2000). In a large Norwegian cohort adolescent study, participants performing physical activity 2-3 times per week decreased the odds of NP for both males and females (OR 0.47, 95% CI 0.35 - 0.63 and OR 0.61, 95% CI 0.50 - 0.73). Adolescents who performed physical activity 4-7 days a week had an even further decreased odds of NP for both males and females (OR .44, 95% CI .32 -.61 and OR .55 95% CI .44 - .69) (Myrtveit et al., 2014). The discordant findings of these studies suggest the nature, intensity and duration of exercise may have differing effects on the relationship between NP and exercise. Whilst some forms of exercise such as upper limb exercise may be of benefit in reducing the risk of NP (perhaps via long term strengthening), the relationship between cardiovascular exercise and NP appears less clear. Further prospective studies examining different forms of exercise and the frequency and continuance of exercise on NP are warranted.

Smoking: Cigarette smoking at the age of 14 was not a risk factor for NP at 17 in the West Australian (Raine) cohort study after controlling for psychosocial factors (OR 2.7, 95% CI 0.91 – 7.90) (Gill et al., 2014). However smoking cigarettes was associated with NP in a Finnish adolescent population (Vikat et al., 2000). As compared to participants that had never tried smoking, the odds of NP increased with the number of cigarettes smoked: those who had smoked 2-50 cigarettes ever had increased odds of NP (OR 1.2, 95% CI not reported); participants that had tried more than 50 cigarettes ever had increased risk of NP (OR 1.5, 95% CI not reported); those who smoked less than 10 cigarettes daily had increased odds of NP (OR 1.6, 95% CI not reported); the odds of NP was further increased if participants smoked 10 or more cigarettes daily (OR 1.9, 95% CI not reported) (Vikat et al., 2000). However the Finnish study did not adjust for psychosocial factors and likely explains the differences in findings of the two studies. A range of mechanisms have been proposed to explain the link between cigarette smoking and chronic pain and include altered processing of pain, structural damage to the other systems, the association with depression and other psychological factors, increased likelihood of opioid use and other effects such as exposure to carbon monoxide (Shi et al., 2010).

1.2.4 Psychological factors:

The relationship between NP and different psychological factors has been studied in depth.

Specific psychological factors that have been measured differ across studies. Psychological distress as measured by the 12 item General Health Questionnaire has been shown to be a risk factor for NP in a large British adult population cohort (Croft et al., 2001). The risk of NP for participants with the highest scores of psychological distress (highest quartile) was twice as high as those in the lowest quartile (RR 2.0, 95% CI 1.4 - 2.8). Similarly mental health status (as measured by the Mental Health Index from the 36-Item Short Form Health Survey) was a risk factor for NP in Canadian adolescents per one standard deviation decrease in score (OR 1.18, 95% CI 1.42 - 2.31) (Ehrmann Feldman et al., 2002). Depression as measured using the Centre for Epidemiological Studies Depression Scale has been associated with NP in a Dutch adolescent population (OR 1.9, 95% CI 1.5 – 2.5) (Diepenmaat et al., 2006). In addition, 14 year old adolescents enrolled in the West Australian (Raine) study with higher somatic, anxious/depressed and withdrawn components of internalising disorders (as measured by the Youth Self Report) had a greater risk of NP as compared to those with lower components of internalising disorders (Somatic multinomial odds ratio (MOR) 1.73, 95% CI 1.46 – 2.05; Anxious/ depressed MOR 1.43, 95% CI 1.20 – 1.70; withdrawn MOR 1.52 95% CI 1.23 – 1.88) (Rees et al., 2011). The same cohort also completed the Beck Depression Inventory at the age of 14, after controlling for relevant biological and social covariates, girls with high or medium depressed mood reported greater odds of NP than girls with low depressed mood (High depression OR 8.63, 95% CI 4.39 -16.98; Medium depression OR 4.23, 95% CI 3.21- 7.92). This relationship was also significant in boys although was not as strong (High depression OR 4.26, 95% CI 2.77 – 6.57; Medium depression OR 2.29, 95% CI 1.59 -3.29) (Pollock et al., 2011). A systematic review that looked at the course and prognosis of NP, psychological factors such as passive coping (worry and fear avoidance) and coping patterns that involved getting angry or frustrated were the strongest prognostic factors of poor outcome for those with NP in the general population (Carroll et al., 2008). Another systematic review also of the general population, concluded that poor psychological health is a risk factor for NP and is often associated with it (Hogg-Johnson et al., 2009). However, two more recent systematic reviews (one of the general population, the second of office workers) investigated risk factors for non-specific NP and focussed on prospective cohort studies (McLean et al., 2010, Paksaichol et al., 2012). Both concluded there was no high quality evidence to support psychological factors as a risk for future NP. The more stringent inclusion criteria and evaluation of the quality of the studies of the latter two reviews explains the difference in conclusions to the first. The contemporary understanding of the link between pain and depression relates to the central nervous system, which undergoes long-term plastic changes associated with both chronic pain and depression (Doan et al., 2015). Shared central nervous system neuro-circuits and neurochemicals may be the basis for these changes. There is good evidence that psychological factors are both associated to NP and a risk factor for NP. This highlights that psychological factors should be considered when examining NP.

1.2.5 Occupational factors:

Occupation: There is evidence from systematic reviews that the prevalence of NP varies across different occupations (Cote et al., 2009). A systematic review of NP in workers reported that office and computer workers had the highest incidence of NP (Cote et al., 2009). However the definitions of NP included in the review varied and may have influenced the reported incidence rates. A large cross sectional study of 63,629 employed workers in the United States profiled the relative risk of NP in different occupations (Yang et al., 2015). After controlling for demographic characteristics, leisure time physical activities, socio-economic status and serious psychological distress, as compared to workers in the architecture and engineering occupation group which had the lowest prevalence, the top five occupational groups with significantly higher prevalence of NP were; military specific (OR 2.50, 95% CI 1.17 – 5.35), arts, design, entertainment, sports and media (OR 1.70, 95% CI 1.34 – 2.17), life, physical and social science (OR 1.67, 95% CI 1.33 – 2.11) health care support (OR 1.55 95% CI 1.23 – 1.97) and installation, maintenance and repair (OR 1.54, 95% CI 1.21 – 1.96). It has been postulated that the mechanism for work specific factors associated with NP are due to static neck flexion postures, repetitive movements of the arms and sitting posture (Ariens et al., 2001a).

Workplace physical exposures: A large prospective design study in the Netherlands reported sitting at work for more than 95% of working time doubled the risk of NP as compared to sitting less than 1% of the time (RR 2.34, 95% CI 1.05 – 5.21) after taking potential confounding physical factors, psychological factors, age, sex and body mass index (BMI) into account (Ariens et al., 2001a). The study went on to further characterise particular angular measures of sitting posture as a potential risk factor for NP (Section 1.5.2). A systematic review of the literature reported there was only low quality evidence that NP was associated with workplace physical exposures including increased amount of computer work, work above the head, long periods of repetitive work with the hands and vibration (Ariens et al., 2000). The authors reported there was a high risk of bias in most studies included in the review. Unlike the prospective study by Ariens et al. (2001a) studies included in the systematic review (Ariens et al., 2000) did not take other potential related factors into account.

Workplace psychosocial factors: High quantitative job demands (RR 2.14, 95% CI 1.28 - 3.58) and low co-worker support (RR 2.43, 95% CI 0.91 – 4.22) have both been found to be risk factors for NP in a large 3 year prospective study conducted in the Netherlands, that included multiple work types and adjusted for age, gender and the time spent in a minimum of 45 degrees of neck flexion (Ariens et al., 2001a). Conversely a study of 53 Australian office workers did not find psychosocial work factors as measured by the Job Content Questionnaire which measures psychosocial stress at work across 3 domains, mental workload, decision latitude and social support, to be a risk for new incident NP over one year. Values were dichotomised at the median score on the Job Content Questionnaire of 159 (Hazard ratio (HR) 1.1, 95% CI 0.98 – 1.03) (Hush et al., 2009). In the same study, workers with high psychological stress (scoring 5 or more on the stress subscale of the 21 item Depression Anxiety and Stress Scale questionnaire) had, on average a 1.6 greater probability of NP after adjusting for other related factors (HR 1.64, 95% CI 0.66 – 4.07) but this effect did not remain in the final model (HR not reported) (Hush et al., 2009). One potential drawback of this study is that it would be difficult to separate some of the general psychological stress in usual life from workplace psychological stress. The results from the two studies (Ariens et al., 2001b, Hush et al., 2009) appear to conflict. The different findings of these studies are most likely explained by the larger numbers of subjects included in the Dutch study (977 versus 53 in the Australian study). Additionally a wide range of work was included in the Dutch study (versus only office workers in the Australian study) and it also had a longer follow up period (3 years versus 1 year) potentially giving it greater power.

A recent systematic review of the prospective literature, reported that there is moderate evidence that psychological factors are not a risk factor for NP in office workers (Paksaichol et al., 2012). Shared central nervous system pathways are likely to underlie potential links between psychological distress and NP (Doan et al., 2015).

Hours of work: A large cross sectional study conducted in the USA reported that greater hours of employed work were associated with increased odds of NP (Yang et al., 2015). Compared to working 40 hours per week, people who worked 46 – 59 hours (OR 1.20, 95% CI 1.10 – 1.30) and 60 or more hours per week (OR 1.35, 95% CI 1.21 – 1.51) had greater odds of NP after controlling for demographic characteristics, social economic status, leisure time physical activities, serious psychological distress and occupation. The authors hypothesised that long work hours could relate to prolonged exposure to physical and psychosocial work factors in the work place or insufficient recovery time.

1.2.6 Social factors:

A systematic review of the general population which included both adults and children reported the majority of evidence reflects no association between NP and socioeconomic status or it's correlates (education, income, home ownership and social deprivation) (Hogg-Johnson et al., 2009). However one large epidemiological study in Finland found that 16 – 18 year old boys who were not enrolled in school had the highest prevalence of NP, whilst boys studying at secondary school had a higher prevalence of NP than boys studying at other types of schools, but the strength of this association was not reported (Vikat et al., 2000). No such differences were found amongst girls. The differences did not remain significant following adjustment for other health variables. With, at best, only a weak association in the univariable model, there is a lack of evidence of the link between school enrolment/ school achievement and NP.

There is some prospective evidence that working adolescents were almost twice as likely to develop NP over a 12 month period, as compared to those not working (OR 2.01, 95% CI 1.04 – 3.88), however the reason for this was unclear (Ehrmann Feldman et al., 2002). Conversely employment status was not a risk factor for new incidence of NP in a study of 7609 British adults after adjusting for other related factors (Croft et al., 2001).

1.2.7 Other factors:

Neck pain, back pain and co-morbid pain: There is strong evidence from a large British prospective study of 7609 adults that previous history of perceived neck injury is a risk factor for the onset of NP (RR 1.7, 95% CI 1.2 – 2.5) (Croft et al., 2001). Additionally a Finnish longitudinal cohort study of 547 participants has shown that the presence of NP in late adolescence was associated with NP 7 years later as a young adult after adjusting for other related factors (RR 1.8, 95% CI 1.1 – 2.8) (Siivola et al., 2004). The finding that previous NP predicts future NP is consistent with pre-existing musculoskeletal pain predicting future musculoskeletal pain. For example, there is evidence that past history of low back pain predicts future low back pain (Janwantanakul et al., 2012).

There is also evidence that pain elsewhere is a risk factor for NP. A prospective study of 7609 British adults found that low back pain is a risk factor for NP (OR 1.7, 95% CI 1.3 -2.1) (Croft et al., 2001). This is supported by a Finnish epidemiological study of 11,095 12 – 18 year olds that found low back pain to be associated with NP (OR 4.3, 95% CI not reported) (Vikat et al., 2000). In addition, there is good evidence from a British epidemiological study of 6038 adults that six upper limb pain sites were associated with NP (Walker-Bone et al., 2004). As compared to participants without NP, the odds of NP ranged from OR 8.1, 95% CI 7.5 – 4.7 in the non dominant shoulder to OR 3.6, 95% CI 3.0 – 4.2 in the non dominant wrist/ hand (Walker-Bone et al., 2004).

Similarly, general health appears to be related to NP. In a British prospective study of 7609 adults, self-assessed health, rated excellent to poor across four categories, demonstrated a linear increase in risk of NP (Croft et al., 2001). Those who rated themselves to have poor health were almost 2.4 times as likely to experience NP as compared to those who rated themselves in excellent health (OR 2.4, 95% CI 1.4 – 3.9). In concurrence Finnish adolescents with long-term illness were found to be 1.4 times as likely to experience NP as compared to those without long-term illness (OR 1.4, 95% CI not reported) (Vikat et al., 2000).

One possible explanation for the report of multiple pain sites may be that some individuals may have a general decreased threshold to reporting pain. It has also been suggested that reports of multiple areas of pain may be linked to a widespread pain sensitivity, for example chronic NP as result of whiplash injury has been associated with lowered pain thresholds in uninjured tissue (Woolf, 2011).

Wearing glasses/ contact lenses: There is some cross sectional evidence that wearing glasses or contact lenses is associated with NP in a large Finnish adolescent population (OR 1.2, 95% CI not reported) although the reason for this is not clear (Vikat et al., 2000).

Puberty: As compared to the average age for the onset of puberty (14 years), an earlier or late onset of puberty was associated with NP in a large Finnish adolescent cross sectional study (early onset OR 1.3, 95% CI not recorded; late onset OR 0.8, 95% CI not recorded)

(Vikat et al., 2000). However, after adjusting for other related factors this effect was lost. Another study of 254 Norwegian female adolescents reported that NP was not associated to the stage of puberty (Wedderkopp et al., 2005).

1.2.8 Anthropometric factors

Height: A longitudinal cohort study of 855 Finnish children reported that shorter height at age 11 was a risk factor for NP at the age of 22 (OR per 1 standard deviation (SD) of body height 0.78, 95% CI 0.62 - 0.97). When analysing the cross sectional data at age 22 the association between small height and higher odds of NP continued (OR per 1 SD of body height 0.62, 95% CI 0.45 - 0.86) (Poussa et al., 2005). The reasons were not clear, but the authors suggested the mechanism by which smaller people might be of greater risk of NP is potentially linked to ergonomics of work stations/ classroom desks, with shorter individuals using shoulder elevation to compensate for work stations that are "too high" (Poussa et al., 2005). However there is a lack of evidence for this proposal. In contrast other studies conducted in Finland have not found height in adolescence to be a risk factor for NP seven years later (Siivola et al., 2004) or associative factor for NP in two separate cohorts of 718 15 – 18 year olds and 11,095 12 – 18 year olds (Niemi et al., 1996, Vikat et al., 2000). As such, the link between height and NP remains unclear.

Body mass index: One prospective study of 769 Dutch nursing home and elderly care workers reported obesity (BMI > 30 kilograms/metre^2 (kg/m^2) significantly increased risk of NP as compared to those with BMI <30kg/m^2 (OR 2.23, 95% CI 1.29 – 3.87) (Luime et al., 2004). Conversely increased BMI (> 27.5kg/m^2) was not a risk factor for an incident of NP in a large British prospective study of the general population as compared to those with a low BMI (<22.5kg/m^2 as compared to those with a BMI ≥22.5kg/m^2) (OR 1.1, 95% CI .8 – 1.5) (Croft et al., 2001). The difference in outcome may be related to specific occupational factors confounding the outcome of the Swedish study. Furthermore the British study used 4 categories of BMI and compared them to the lowest category (<22.5 kg/m^2) with the highest BMI category defined as >27.5 kg/m^2 whereas the Swedish study dichotomised data into two categories above and below 30 kg/m^2.

A systematic review reported that the majority of evidence suggests that there is no relationship between BMI and the prevalence of NP (Hogg-Johnson et al., 2009). One cross sectional study reported that the prevalence of NP was higher in 12 – 18 year olds in the lowest 15% of BMI as compared to the middle 15-85% (OR 1.3, 95% CI not reported) (Vikat et al., 2000). The disparity in the literature renders the relationship between BMI and NP unclear. Recent studies have explored the possibility that obesity produces a pro-inflammatory state and that pro-inflammatory substrates may contribute to the development of pain (Astita et al., 2015, McVinnie, 2013).

1.2.9 Physical factors:

Muscle performance: Several studies have considered the performance of neck muscles and its association to NP. A specific test of craniocervical flexion (Jull et al., 2008) has been used in the research literature to test graded performance of cervical flexor muscles using pressure biofeedback. The ability to perform the craniocervical flexion test at 5 incremental stages of increasing range with a 10 seconds hold, was significantly poorer in a group of 20 NP participants (median pressure achieved 24 millimetres of mercury (mmHg)) as compared to asymptomatic controls (median pressure achieved 28mmHg) (Chiu et al., 2005). Similarly myoelectric signals (EMG) were detected from sternocleidomastoid muscles during performance of the craniocervical flexion test of 25 asymptomatic controls, 25 whiplash and 25 insidious onset NP participants. The results indicated that both insidious onset NP and whiplash groups had greater shortfalls from pressure targets ($p < .002$) and elevated EMG activity in sternocleidomastoid at 5 stages of the test as compared to the control group (all $p < .05$) (Jull et al., 2004). The results are in concordance with a study of isometric craniocervical flexion strength as measured by a craniocervical flexion dynamometer (O'Leary et al., 2007). Forty six participants with NP were compared to 47 asymptomatic controls. Those with NP were found to have reduced ability to sustain an isometric craniocervical flexion contraction to task failure at 20% (35% deficit) and 50% (27% deficit) of maximum voluntary contraction. Similar to the finding of Jull et al. (2004) the NP group also had poorer accuracy in maintaining their isometric contraction at the designated torque (O'Leary et al., 2007). One study measured EMG activity of the deep cervical muscles of 10 participants with chronic NP and 10 asymptomatic controls using custom electrodes inserted via the nose, fixed by suction to the posterior mucosa of the oropharynx (Falla et al., 2004). Surface EMG also measured activity of sternocleidomastoid and the anterior scalene. When craniocervical flexion was performed the amplitude of deep cervical flexor EMG activity was less for the group with NP than those without NP, and this difference was significant for the higher increments of the task. Concurrent increases in sternocleidomastoid and anterior scalene EMG activity for the group with NP did not reach significance (Falla et al., 2004).

Whilst the evidence suggests that changes in muscle performance during craniocervical flexion are a feature of NP, there is only a modest relationship between pain intensity and superficial muscle activity (O'Leary et al., 2011b). A significant association was found between the intensity of NP and changes in EMG activity at sternocleidomastoid and anterior scalene recorded during 5 stages of the craniocervical flexion test in 84 participants with chronic NP. However there was no association between EMG and duration of NP or disability as measured by the Neck Disability Index (O'Leary et al., 2011b). The author commented that it is likely that many factors such as compensatory mechanisms for coinciding deficits in deep neck flexors, changes in muscle spindle sensitivity, alterations in cortical excitability, and changes to the descending drive to muscles contribute to altered muscle performance observed in NP (O'Leary et al., 2011b).

Other studies have looked at muscle performance of the neck extensor muscles in NP and no pain groups (Cagnie et al., 2007, Edmondston et al., 2011b, Lee et al., 2005, O'Leary et al., 2011a) and the ratio of flexor to extensor muscle performance (Cagnie et al., 2007). A Dutch cross sectional study of 55 participants found there was reduced muscle endurance of the extensor neck muscles (as measured by the duration of time to hold a neck extensor muscle endurance test in prone) in treated and untreated NP groups as compared to a no pain group (treated NP mean (SD): 350.4 seconds (199.3 seconds); non treated NP mean (SD): 480.8 seconds (167.8); no NP mean (SD): 608.3 seconds (39.9 seconds)) (Lee et al., 2005). Conversely an Australian cross sectional study reported 13 female participants with postural NP did not display accelerated fatigue or differ in extensor muscle endurance as compared to controls when performing a neck extensor endurance test in prone with 2kg suspended from the head (NP mean (interquartile range (IQR)): 165 seconds (111 – 240 seconds); no NP mean (IQR): 228 seconds (190 – 240)) (Edmondston et al., 2011a). The authors noted a larger variability in measures of muscle endurance, which, they hypothesised, might be due to patient specific muscle function impairments associated with NP. Potentially the small number of participants affected the power of the study. Peak torque production for extension and extension/flexion ratios (as measured by a Biodex isokinetic dynamometer) were significantly lower in a chronic NP group of 30 females as compared to 48 females without NP (Extension NP mean (SD): 22.3 Newton metres (Nm) (5.6Nm); no NP mean (SD): 26.5Nm (6.2Nm); Extension/flexion ratios NP mean

(SD) 1.35Nm (0.29Nm); no NP mean (SD) 1.59Nm (0.38)) (Cagnie et al., 2007). There was no significant difference in flexion strength between the NP and the asymptomatic group. However the results may only be applicable to females.

One study looked at activation pattern of the neck extensor muscles using functional MRI (O'Leary et al., 2011a). There were differences in the activation pattern of the extensor muscles in participants with NP as compared to an asymptomatic group when an isometric contraction was performed in prone in a 'neutral' neck position. However differences were observed in only 3 of 7 muscle regions (splenius capitus at C7-T1, multifidus/semispinalis cervicis at C5/6 and C7/T1). The authors speculated that deficiencies in low cervical extensor muscle activity may be a problem in some patients with NP (O'Leary 2011). However, there was a greater number of females in the NP group which may have skewed results.

Whilst there is a preponderance of evidence to support an association between NP and altered muscle performance of the cervical flexors and extensors, the cross sectional nature of the study designs cannot determine the role of muscle performance in the causality of NP. It has been proposed that fatigue of neck musculature may in turn lead to muscle pain (Chaffin, 1973).

Sagittal posture: Sagittal postural alignment as a risk factor for NP has long been debated. There is disparity in the literature. Individual biases and low levels of evidence appear to give rise to the divergence of opinion (Christensen and Hartvigsen, 2008). The evidence for neck posture as a risk factor for NP is considered in more detail in Section 1.5.2 and the evidence for neck posture as an associative factor for NP is detailed in Section 1.5.3.

1.3 Potential mechanisms that link posture and neck pain

Despite a lack of empirical evidence in the research literature (Silva et al., 2010b), there is a common societal belief that posture is the cause of NP (Morrison, 2016, Pietrangelo, 2016). Poor posture has also been, anecdotally, linked to NP in the scientific literature (Griegel-Morris et al., 1992). Adolescents with NP have identified posture as a highly important contributing factor to their pain (Cho et al., 2003). A few different biomechanical and physiological mechanisms have been hypothesised in the literature to link sagittal posture to NP.

1.3.1 Habitual posture and task posture definitions:

In this thesis habitual posture is defined as the posture an individual usually adopts (and can be measured in sitting or standing). Task posture is defined as transient changes to habitual posture that result as a consequence of different tasks. The position of the head will be influenced by the requirements of vision (Jull, 2008). For example painting the ceiling may require a posture with the neck held in extension, whilst reading a book may require a posture with the neck held in flexion. It has been suggested that transient changes in neck posture as result of task demands may result in neuromuscular adaptive changes and are associated with changes to habitual posture (Straker et al., 2007).

1.3.2 Hypothesised mechanism for posture link to neck pain:

It is believed that deviation from 'ideal' posture places excessive stress or strain on the myofascial and articular structures (Grimmer-Somers et al., 2008) (see Section 1.3.5 for full description of the concept of the 'ideal' posture). The features previously found to exist following a change of neck posture into a more flexed posture include increased gravitational moment (Szeto et al., 2005a, Edmondston et al., 2011b), increased torque around C7 (Pheasant, 1988) and altered muscular activation (Caneiro et al., 2010, Szeto et al., 2005b) of the superficial cervical extensors to support the weight of the head (Straker et al., 1997, Burgess-Limerick et al., 1999). It has been proposed that the consequential increase in muscle load results in earlier fatigue of neck musculature resulting in the muscle being a source of NP (Chaffin, 1973).

Additionally, sustained flexion of the neck can result in significant creep of the cervical spine in subjects with and without NP (Gooch, 1993). Similar conditions of low-level loading have been mimicked in the feline lumbar spine resulting in the expression of pro-inflammatory cytokines (Solomonow et al., 2012). Cytokine release may explain on-going pain in visco-elastic structures in the cervical spine; however there is no current evidence that this occurs in humans.

It has also been proposed that head tilt position is linked to NP and headaches (Watson and Trott, 1993). In the upright position, if the head is tilted upwards the centre of mass of the head and the head and neck combined remains anterior to the centre of rotation (Burgess-Limerick et al., 1999). It is hypothesised the deep cervical extensor muscles around the C0/1 must work to counter flexion moment, but in a mechanically disadvantaged (shortened) position (Burgess-Limerick et al., 1999), potentially resulting in fatigue and thus pain. Pain could also result as a consequence of excessive or prolonged stretch of the joint capsule (Cavanaugh et al., 2006).

It has also been proposed that posture with joints positioned at end range could be a risk factor for NP (Straker et al., 2008). Hypothetically, pain associated with an erect posture may result from continued activation of the erector spinae muscle complex (Caneiro et al., 2010) which could in turn expose the cervico-thoracic spine to increased loading through their multi-segmental attachments. Alternatively pain may originate from the muscles fibres that remain active for long periods of time, which consequently overload leading to pain (Cote and Hoeger Bement, 2010). To date, however there is a lack of evidence for this.

1.3.3 Posture re-education for the management of neck pain:

As a result of the perception that posture is a risk factor for NP, treatments that target posture to reduce or prevent NP are commonplace. The objective is to decrease compressive loading of the cervical joints and facilitate postural musculature to improve the functional support of the spine (Falla et al., 2007b). Interventions can change muscle activity and posture. There is evidence that deep cervical flexor muscle activity in females with chronic NP improves with therapist facilitated instructions to sit in an “upright neutral position” as compared to non-specific postural advice (Falla et al., 2007b). A combination of strength training and postural retraining can change neck postural alignment in swimmers with chronic shoulder pain (Lynch et al., 2010). Similarly endurance strength training of the deep neck flexors can improve the ability to maintain a more upright alignment during prolonged sitting in females with chronic NP (Falla et al., 2007a). However there is a lack of evidence to demonstrate that a change in posture leads to a change in pain. A functional postural exercise in upright sitting with a neck-lengthening manoeuvre was taught to 20 participants with persistent NP. Two weeks of training with this exercise did not alter pain and disability measures, although there was an improvement in the craniocervical flexion test performance (Beer et al., 2012). A recent randomised controlled trial (RCT) on whiplash associated NP found that a comprehensive exercise programme (that included posture re-education, strengthening of neck flexors and extensors and sensorimotor exercises) was no more effective than simple advice (Michaleff et al., 2014). However posture was not an outcome measure in this study and the advice booklet used in this trial (Jull, 2014), also gave some generic posture correction advice, which may have negated any true control. A RCT on cervicogenic a headache patient group showed that despite including postural exercises into an exercise programme there was no change in neck flexion angular measures of posture after treatment but there was a significant change in headache symptoms suggesting that the change in symptoms was not mediated by a change in posture (Jull et al., 2002). Currently there is a lack of strong evidence that changing posture has a direct benefit on pain reduction.

In summary a number of theories regarding the mechanisms that could link neck posture to NP have been proposed. It has been postulated that the amount of sagittal neck flexion/extension and the degree of head tilt may be important. It is believed that these aspects of posture can affect the gravitation moment, levels of muscle activity and joint load, however there is a lack of evidence for this belief. The relationship between neck posture and NP is presented in Section 1.5, Neck posture and neck pain.

1.3.4 Methodologies for the measurement of sagittal neck posture:

Various methods have been used to measure sagittal neck posture. There are three major considerations when assessing sagittal neck posture; (i) Angular displacements related to gross flexion/extension of the neck and head tilt, (ii) The translational position of the head relative to the body, and (iii) Segmental position between adjacent vertebrae, and subsequent spinal curvature (ie lordosis).

Radiographic examination: Radiographic examination is considered the gold standard for postural measurement (Gadotti and Magee, 2008). Postural data can be calculated in different ways, but there is no single universal method to measure sagittal cervical spine posture (Radcliff et al., 2011). Different anatomical markers can be used, thereby making direct comparison between studies challenging. Radiographic examination can assess angles between vertebrae, translational distances and intersegmental relationships of adjacent vertebrae along with the sagittal spinal curvature (i.e. the curvature bending backwards or forwards). The intra-subject test-retest reliability of radiographic assessment of craniocervical posture has been reported as good (intra class correlation co-efficient (ICC) 0.90-0.98 and standard error of the mean (SEM), 0.25-0.70) (Gadotti and Magee, 2013a).

Methods to calculate the shape of the cervical spine lordosis include measuring the Cobb angle (McAviney et al., 2005, Harrison et al., 2004), modelling the cervical lordosis to a circle (Harrison et al., 2004) or the use of complex geometrical models (Takeshita et al., 2001). There was a significant association between x-ray angular measures and the curvature of the cervical spine when x-rays were visually categorised into three groups: a lordotic curvature, a predominately straight one and a partially reversed curvature (defined as a high cervical lordosis and a low cervical kyphosis) (Visscher et al., 1998).

It has been proposed that the apex of the lordosis is at approximately C4-C5 (Kuntz et al., 2007, Xu-hui et al., 2009). Due to the differing methods of measurement however, there is disagreement in the clinically normal range for cervical lordosis with authors calculating variable figures. In a review of the literature, the pooled estimates from three studies of asymptomatic adult participants that measured the cervical lordosis from C2 – 7 (angle between the line drawn parallel to the posterior border of C2 vertebral body and a line drawn parallel to the posterior border of C7 vertebral body) found a mean of 17° and variance of 14° (Kuntz et al., 2007). Whereas an earlier literature review presented data from two studies that used the same measure of cervical lordosis from C2 -7 and reported the mean lordosis to be 21°- 22° (Harrison et al., 1996)

In the upper cervical spine, measurement of C0-C2 alignment is most commonly derived from MacGregors line (an angle between the line from the posterosuperior aspect of the hard palate to the most caudal point on the midline of the occiput and the line tangential to the inferior end plate of C2) (Radcliff et al., 2011). Normal mean angulation calculated by the pooled estimates from two studies of asymptomatic adults is reported to be 14° lordosis (variance 7°) (Kuntz et al., 2007).

Despite radiographs being accepted as the gold standard method for postural measurement there is no standard way posture is calculated from radiographic images. Other disadvantages of radiology include exposure of subjects to ionising radiation and cost.

Sagittal photographs: The use of photography to evaluate posture is less expensive and safer than X-ray evaluation (Chen and Lee, 1997). It also considered a more objective method than visual observation (Gadotti and Magee, 2013b) and is suitable to use in large population studies (Perry, 2008). In this method, markers are placed over relevant anatomical landmarks and postural angular and displacement measures can be measured digitally or by goniometry. There is satisfactory inter-rater and intra-rater reliability (ICCs ranging from 0.37 to 0.68) for measuring sagittal postures of the thoracic and cervical spine in adolescent (Perry, 2008) and adult populations (ICCs ranging from 0.80 to 0.87) (Lau et al., 2010). Posture analysis from motion analysis systems using surface markers is also possible, though requires more extensive laboratory facilities than sagittal photography (Szeto et al., 2005b).

Evaluation of the validity of surface landmarking photographic assessment as compared to radiographic measures is still lacking, with previous studies failing to compare the same posture constructs (eg inclination of the neck or position of the head in relation to the neck) (Gadotti and Magee, 2013b). Previous studies have shown poor correlation between bony landmarking and surface landmarking in the cervical spine (Johnson, 1998, Refshauge et al., 1994). Differences are most likely due to length of spinous processes and soft tissue thickness. However, when evaluating angular measures from C7 to C2, radiography and surface landmark angular measures have moderate correlation, and when measured from T2 to C2 there is a strong correlation (Refshauge et al., 1994). This infers that surface landmarking and radiological examination establish similar results when evaluating neck flexion measures. Some difficulties exist in landmarking the C2 spinous process due to soft tissue thickness (Gadotti and Magee, 2013b, Refshauge et al., 1994), whereas a more reliable landmark such as the tragus of the ear may decrease the surface landmark error and potentially improve correlation.

As with radiological studies, there are a variety of anatomical reference points making comparison between studies challenging. The disadvantage of photographic assessment methods is that it does not assess the intersegmental position of adjacent vertebra and as such may not capture some of the complex alterations of neck and head posture (Gadotti and Magee, 2013b).

Other methods to assess resting head posture via the photographic methods include translational measurement from a plumb line to the eye (Harrison et al., 1996) or to a standardised reference point (Hanten et al., 1991, Hanten et al., 2000, Grimmer, 1997). However, use of translation variables only is likely to miss the relationship between adjacent spinal segments and angular measures of head and neck flexion that have been proposed to be of importance in the relationship of neck posture to NP (Burgess-Limerick et al., 1999).

Visual observation of posture: Scales to characterise head posture are commonly used in clinical practice (Griegel-Morris et al., 1992, Silva et al., 2010a). Lateral photographs (Silva et al., 2010a) and X-Rays (Visscher et al., 1998) can also be characterised in a similar fashion describing the amount of lordosis and forward positioning of the head. However the assessment of posture by observation of photographs and a four-category scale has shown poor reliability and validity with K values for intra-rater reliability varying between 0.19 and 0.81 and for inter-rater reliability between 0.02 and 0.07 for sagittal posture attributes (Silva et al., 2010a).

1.3.5 "Ideal" neck posture:

Postural evaluation is regarded as an integral part of the assessment of patients presenting with NP (Petty and Moore, 1998, Grant, 1994, Kendall et al., 1993, Saunders and Saunders, 1995). Most texts refer to the plumb line theory presented by Kendall et al. (1993) to appraise 'ideal' spine posture in relation to the line of gravity. It has been proposed that in this posture the head should sit in a 'well-balanced' position, a 'normal' cervical lordosis should be maintained and the head should not be tilted up or down (Kendall et al., 1993, Petty and Moore, 1998). However, this assumption was based on clinical belief and lacks validation. Furthermore upright "neutral" posture has been described as a goal of rehabilitation, but to date the position of "neutral" has not been defined (Jull, 2008).

Habitual posture isn't 'ideal' posture: Regardless of the way it is measured and the position it is measured in (sitting or standing), habitual posture varies across the population. There is a wide variation in the neck posture of asymptomatic subjects whether measured by x-ray, photographic study or visual observation (Gore, 2001, Gore et al., 1986, Grimmer, 1997). On average, when normal adult participants were standing, the neck tilt angle between the horizontal and the line joining the tragus of the ear and surface landmark of C7 has been reported to be 49° (95% CI 48° - 50°) (Raine and Twomey, 1994) 52° (SD 5°) of flexion (Raine and Twomey, 1997), and when seated 49° (SD 3°) (Watson and Trott, 1993). Similarly in a 14-year-old adolescent population the mean neck flexion angle (in sitting) was 52° (SD 9°) (Straker et al., 2008). Another study measured sitting neck posture by linear excursion and found in a cohort of 427 participants without NP there was not a single subject that held their resting head position in 'ideal' alignment (Grimmer, 1997). The result highlighted that habitual cervical spine posture in asymptomatic individuals is not typically the "ideal" posture presented by Kendall et al. (1993).

Deviations in cervical spine posture: The aforementioned angular and translational attributes of neck posture can occur in combination or isolation (Harrison et al., 1999) to effect the position of the head on the body and the angle of the cervical spine. The lower cervical segments will be further influenced by the position of the thoracic and lumbar spine (Caneiro et al., 2010, Edmondston et al., 2011b, Berthonnaud et al., 2005), and by the subject's position (e.g. sitting or standing) (see Section 1.4.4 Sitting versus standing posture). A number of potential subgroups of neck posture have been ascertained from x-ray and/or sagittal photograph studies (Section 1.3.5.3, Potential subgroups of neck posture).

Potential subgroups of neck posture: It is likely that clusters of cervical spine postures exist, such as those that have been identified in the lumbar spine (Smith et al., 2008a, Roussouly and Nnadi, 2010). To date this premise has not been thoroughly investigated in the cervical spine. Deviation of the neck and head anteriorly from Kendall's (Kendall et al., 1993) plumb line is commonly considered a forward head posture (Kendall et al., 1993, Sahrmann, 2002). The literature is in agreement that forward head posture occurs via a combination of upper thoracic flexion and cervical spine flexion (Darnell, 1983, Grimmer-Somers et al., 2008). However two versions of forward head posture have been described, one with and one without extension of the upper cervical spine (Grimmer, 1996). Alternatively forward head posture may exist in moderate and extreme forms (Grimmer, 1996, Grimmer-Somers et al., 2008). However, most studies examining neck posture refer to forward head posture as an angle of neck flexion and do not take the thoracic spine position or the position of the head into account, and as such may be combining two separate groups into one. On the opposite extreme of forward head posture, a very upright position with the head held close to the vertical axis may exist (Brink et al., 2009).

The existence of the above postures has, in part, been confirmed in a radiographic study. Radiographs of 54 21 – 31 year old participants were visually categorised into three subgroups based on the shape of the cervical spine curvature and labelled lordotic, straight or partially reversed (a high cervical lordosis and a low cervical kyphosis). A significant relationship was confirmed between the subgroups and a postural angular measure (a surrogate measure of neck flexion C6 to C1) (Visscher et al., 1998). The three subgroups could be interpreted as an upright posture along with a moderate and extreme form of forward head posture; alternatively the group in the middle could represent a more ‘neutral’ posture. The head position was not measured in Visscher et al. (1998) study, therefore the forward head posture distinguished by the head tilt described by Grimmer (1996) could not be ratified. Although there is a lack of consensus to what constitutes ‘neutral’ neck posture (Jull, 2008), it is likely that this subgroup exists as an intermediate posture somewhere between the forward head posture and upright posture extremes. Thus, it is plausible there are four potential subgroups of neck posture; two types of forward head posture, an upright neck posture and an intermediate neck posture.

In summary, there is a broadly accepted view that there are different deviations in cervical spine posture. Due to a lack of consistency in the literature, postures where the head is positioned in a more forward position are often grouped together. A consistent approach to investigating discrete differences of cervical spine posture is required to determine if subgroups of neck posture hinted at in the literature exist.

1.4 Multidimensional factors associated with neck posture

Habitual posture can vary between different people. The influences of physical, ergonomic demands, lifestyle and psychological factors have been considered in relation to posture. The body of evidence is drawn from cross sectional studies with some associative factors investigated in large cohort studies, however the majority of information is derived from smaller clinical cross sectional studies.

1.4.1 Sex:

Male and female posture differs in both adolescent and adult populations. Large cohort studies have consistently shown females sit in more erect (upright) postures (O'Sullivan et al., 2006, O'Sullivan et al., 2011b, Straker et al., 2009, Straker et al., 2008). In one smaller cross sectional study, it has also been established that adult females tend to sit with their head in a more forward position than males when the position of head was measured as the distance from full retraction to the resting position and divided by the linear range of motion from retraction to protraction (Hanten et al., 1991). However males hold their heads a greater linear distance forwards from a wall when standing against it (Hanten et al., 1991). The apparent differences may be as result of a larger head size in men. Conversely other studies have found that angular measures of neck and head tilt are similar between genders (Raine and Twomey, 1997, Raine and Twomey, 1994). It is likely the differences in findings relate to the different methods of measurement used in the study by Hanten et al.

(1991) as compared to the studies by Raine and Twomey (Raine and Twomey, 1994, Raine and Twomey, 1997) (i.e. translational versus angular measures).

1.4.2 Age:

The shape of the spine changes throughout childhood and into adulthood. The cervical lordosis decreases with increasing age between the ages of 8 and 15 (Hellsing et al., 1987), whilst the thoracic kyphosis increases from the age of 8 years to 14 years (Willner and Johnson, 1983). Young adults generally have less cervical lordosis than older adults (Gore et al., 1986). As the spine ages the habitual neck posture measured in standing appears to become one of a more forward head position (Silva et al., 2009). Whereas in sitting, older adults tend to have a significantly increased thoracic kyphosis and decreased lumbar spine flexion than younger adults (Kuo et al., 2009).

1.4.3 The influence of Lumbar spine and thoracic posture in sitting:

With-in subjects designed studies have been performed to determine the influence of lumbar spine posture on cervical spine posture in adults (Caneiro et al., 2010, Black et al., 1996). As compared to lumbo-pelvic neutral and habitual posture, slump sitting posture increased the amount of thoracic and head/neck flexion with greater anterior translation of the head in adults (Caneiro et al., 2010, Edmondston et al., 2011b). A thoracic upright position increased thoracic extension and decreased the head/neck flexion with a trend towards posterior translation of the head (Caneiro et al., 2010). A neutral lumbo-pelvic position was associated with an upright neck alignment (Caneiro et al., 2010). A cross sectional study reported a similar association between increased thoracic flexion and neck flexion with upper cervical spine extension, however no association between the thoracic and lumbar spine angles was found in adults (Kuo et al., 2009). The different finding of the latter study is likely due to participants not being given any instruction on how to position their lumbar spine as opposed to the instruction and guidance techniques used when posture modifications were induced in the with-in subjects studies. The effect of specific manual and verbal facilitated posture guidance has previously been shown to result in different muscle activation pattern as compared to instruction to “sit up straight” spontaneously (Falla et al., 2007b).

1.4.4 Sitting versus standing posture:

One cross sectional study investigated habitual neck posture in both sitting and standing (Hanten et al., 1991). Measurements were obtained using the horizontal distance from the wall to the zygomatic arch. Habitual posture was calculated as the distance from full retraction divided by the distance from full retraction to full protraction. Mean values for habitual posture of the neck were greater in sitting than in standing for both males and females, with the variability also being higher in the sitting data compared to the standing data (Hanten et al., 1991). In another study that investigated the association between adjacent segments of the spine, an interrelationship between the thoracic curve the lumbar spine position was more apparent in standing as compared to sitting (Kuo et al., 2009). Standing demonstrated a correlation of lumbar extension to thoracic flexion, with no such relationship displayed in sitting. Sagittal spinal angles in sitting and standing otherwise demonstrated similar significant chain of correlations, with the position of the neck being influenced by the position of the thoracic spine in both sitting and standing (Kuo et al., 2009). Thus the thoracic spine position should be considered when measuring cervical posture.

1.4.5 Body mass index:

There is some evidence that BMI is associated with sitting spinal posture. Heavier adolescents displayed more flexion of the neck, head and thoracic spine in cross sectional studies (Brink et al., 2009, Brink et al., 2015). Similarly BMI has also been shown to influence sitting lumbar spine posture in young adults (Mitchell et al., 2008).

1.4.6 Psychological factors:

The relationship of psychological factors and thoracolumbar posture has been considered, although no studies have specifically examined associations with neck posture. Perceived self-efficacy and higher levels of behavioural problems were associated with a greater degree of slump sitting in adolescents (O'Sullivan et al., 2011b). The increase in flexion of the thoracic spine could in turn influence neck posture. It has also been postulated that increased cervical flexion in children and adolescents with chronic non-specific musculoskeletal pain may be related to negative psychosocial factors (O'Sullivan et al., 2011a). In two different within-subjects designed studies, adults were asked to adopt different sitting postures; it was found that the slumped position was associated with negative thoughts such as depression (Riskind, 1984), whereas upright postures were associated with gain or positive affects (Riskind, 1984, Wilson and Peper, 2004). Conversely no cross sectional correlation was found between anxiety or depression and head, neck or thoracic spine postural measures in a group of high school students (Brink et al., 2009).

Currently there is no direct evidence for the relationship between psychological factors and neck posture, and further study is warranted.

1.4.7 Task influences on posture:

The nature of a task affects cervical posture. It has been found when adult computer users performed their work, they sat in more neck flexion as compared to their relaxed sitting posture (Szeto et al., 2002). Additionally, back pack use in teenagers has also shown to alter alignment into a more forward head posture (Kim et al., 2008). Different people can adopt diverse postures when performing tasks, this may be as result of intrinsic differences in individuals postural patterns (Szeto et al., 2005b). In addition, the interaction with the environment may alter posture. Previously the height and depth of the chair, angle of the backrest, shape of the seat and use of arm rests has been related to alterations in sitting posture (Harrison et al., 1999).

1.4.8 Pain:

The association between posture and NP could be bidirectional. One theory is that pain could lead to changes in postural alignment following neck injury. An observational report of over 400 trauma cases reported a loss of normal lordotic curvature of the neck on x-ray following neck trauma and hypothesised this was secondary to acute muscle spasm (Clark et al., 1979). However the report was based on opinion alone and did not have comparison films from before the accident. A cross sectional study (Harrison et al., 2004) reported radiographic measures were significantly different between asymptomatic, chronic NP (defined as pain of greater than 12 weeks duration) and acute NP (defined as NP of less than 12 weeks duration) groups. However the normal group had the greatest lordosis, the acute pain group an intermediate lordosis and the chronic NP group the least lordosis. The cervical posture of participants with acute NP appears to be different in the two studies, likely due to the observation nature of the former study (Clark et al., 1979) versus the experimental design of the second study (Harrison et al., 2004).

There is also a proposal that poor posture is the cause of NP (Osmotherly and Attia, 2008, Lau et al., 2010) (Section 3.2 and Section 8). Different mal-adaptive motor responses can be seen where subjects with high NP discomfort appear to adapt differently to physical stressors than those without pain (Szeto et al., 2005b). However a lack of prospective studies makes it difficult to determine if pain alters posture or posture causes pain. Of note, the proposal that pain alters posture describes an association between neck posture and NP in an upright neck posture, whereas the theory that posture causes NP most commonly hypothesises a mechanism of biomechanical strain from the opposite extreme of posture, a forward head posture. This highlights the need for longitudinal research and to clearly differentiate acute NP from on-going or persistent NP symptoms when posture is being investigated as a causation factor. The interaction between pain and posture is complex and will be addressed in detail in Section 1.5 Neck posture and neck pain.

In summary different physical, psychological and task specific factors have a recognised association with cervical spine posture, some of these factors are also related to pain. Further understanding of the relationship between biopsychosocial factors and cervical posture is required. There may be potential for different clusters of neck posture that may have different biopsychosocial profiles.

1.5 Neck posture and neck pain

1.5.1 Evidence for the link between posture and neck pain:

While potential mechanistic links between posture and NP have been discussed (see Section 1.3 and 1.4.8), there is a lack of consensus in studies attempting to correlate posture with NP. The body of evidence is weak, with few well-designed epidemiological studies with prospective designs to draw upon. A systematic review of adolescent and adult groups, found no significant differences in the neck posture of symptomatic and asymptomatic individuals (Silva et al., 2010b). In concurrence, there was insufficient evidence of an association between sagittal spinal curves and NP from studies included in a systematic review of epidemiological literature (Christensen and Hartvigsen, 2008). Another systematic review of adolescent posture and upper quadrant musculoskeletal pain summarised studies that looked at various aspects of posture including postural alignment (Brink and Louw, 2013). The review included studies with pain in the neck, shoulders and upper limbs. Only 4 of 10 studies included in the review defined pain specific to the neck. Whilst the author concluded that there was a link between adolescent posture and upper quadrant musculoskeletal pain, the findings from the review may not be applicable to NP.

1.5.2 Posture as a risk factor for neck pain:

There is a paucity of longitudinal studies examining if posture is a risk factor for NP. One study examined new incidence of NP in 1334 adults who had not experienced NP in the previous 12 months (Ariens et al., 2001a). Participants were enrolled across 43 work places and worked in a wide variety of work roles. No association was found between NP and neck flexion angles measured by video analysis after taking into account the time spent in neck flexion and biopsychosocial factors that could confound the relationship. Despite not reaching significance the authors suggested that there was an increased risk of NP for subjects working with the neck at a minimum of 20° more than 70% of the time (adjusted RR 1.63, 95% CI .70 to 3.82) (Ariens et al., 2001a). However, the study was limited by the analysis being performed at the workplace level rather than individual level, with mean values from a subsample of workers from each workplace used in the association analyses rather than individual data. This may have been the reason for the lack of association observed.

An adolescent cohort study of 104 15-17 year olds attending high school without upper quadrant musculoskeletal pain in the month prior measured neck posture by photographic assessment at a classroom desktop computer. Extreme range (both lower and upper quartiles) neck angles (<35° or > 44° OR 2.8, 95% CI 1.1 – 7.3) or a combination of neck and thoracic angles (<63° or > 71° OR 2.2, 95% CI 1.1 – 5.6) were significant postural risk factors for incident upper quadrant musculoskeletal pain over 6 months (Brink et al., 2009). Another adolescent cohort of 194 15-17 year olds, without upper quadrant musculoskeletal pain in the preceding month had 3D neck posture measures undertaken at a classroom desktop computer (Brink et al., 2015). Increased head flexion was found to be a risk factor for new onset upper quadrant musculoskeletal pain scores (a combined score of the number of areas of pain in the upper quadrant and the severity of pain) that were above the 90th percentile in the data over 12 months (NP score above 90th percentile mean (SD): 82° (8.4), no pain mean (SD): 78° (8°)). As both these studies used outcome measures of upper quadrant pain the results may not be applicable to NP.

1.5.3 Posture and its association to neck pain:

The differences between previous studies investigating the association between neck posture and NP are illustrated in Table 1.2. It is notable that the duration of pain and the definitions of NP are highly varied making comparison between studies challenging.

In the Western Australian (Raine) cohort study of 1593, 14-year-old participants with prolonged NP had decreased lumbar angles (representing increased lumbar extension) (OR 0.99, 95% CI 0.97 – 1.0) and increased anterior pelvic tilt (OR 1.02, 95% CI 1.00 – 1.03) when sitting compared to those without pain after controlling for sex (Straker et al., 2009). However in the same cohort, spinal posture was not associated with lifetime prevalence of NP after controlling for sex (Straker et al., 2008).

Two studies conducted in Portugal examined the association between neck posture and NP in adolescent participants reported conflicting results (Oliveira and Silva, 2016, Ruivo et al., 2014). Two hundred and seventy five 15-17 year olds had postural angular measures evaluated in standing (Ruivo et al., 2014). Participants with regular NP had a significantly lower mean neck tilt angle (angle from the horizontal through C7 to the tragus, representing more neck flexion) than asymptomatic participants (NP mean (SD): 46° (6°), no NP mean (SD): 48° (5°)). No differences between groups were found in the head tilt angle. However, despite a larger proportion of females reporting NP than males (53% versus 19%) and females displaying a 1° greater mean neck flexion resting posture, there was no adjustment for sex which might have influenced the results. In addition there was a lack of clarity for the area of NP used in this study and no clear definition of what constituted "regular NP". Conversely, another study examined the association between a single neck tilt angle (angle from the horizontal through C7 to the tragus) and NP that was present at least once a week in the last 3 months in 70 adolescents aged 15 – 18 (Oliveira and Silva, 2016). Thirty-five participants with NP had a greater mean angle (representing less neck flexion) than 35 asymptomatic participants in standing (NP mean (SD): 47° (5°), no NP mean (SD): 44° (4°)). The small numbers of participants may have affected the power of the study. In addition, there was no adjustment for sex and use of a single measure of neck flexion potentially is not adequate to examine the complexity of posture (Smith et al., 2008a). Despite the contrasting findings of the two Portuguese studies, they highlight that any difference found between NP and non-NP groups are small, and may not be clinically meaningful.

Other cross-sectional studies have found single postural measures to be associated with NP in adult populations (Yip et al., 2008, Osmotherly and Attia, 2008). A small study of thirty-four call centre workers had neck posture measured in sitting (Osmotherly and Attia, 2008). In males, there was an association between a more flexed cervical spine and NP related disability as measured by the Northwick Park NP questionnaire (p = .02), the authors noted females demonstrated a non-significant linear trend in the opposite direction, however no interaction test was performed. The study had 14 males and 20 females enrolled, as such it was potentially underpowered and may not represent a true difference between sex. Similarly 62 subjects with NP and 52 subjects without NP sourced from a physiotherapy waiting list had a neck tilt angle measured in standing (angle from the horizontal through C7 to the tragus) (Yip et al., 2008). Participants with NP demonstrated a smaller neck tilt angle (representing more neck flexion) than asymptomatic participants (NP mean (SD): 50° (6°); no NP mean (SD): 55° (3°)) (Yip et al., 2008). Additionally more neck flexion was associated with greater disability as measured by the Northwick Park NP questionnaire (p = .002) (Yip et al., 2008). However the study included subjects with radicular pain symptoms, which potentially affected the reported disability and pain intensity ratings. Additionally neither the study by (Yip et al., 2008) nor the study by (Osmotherly and Attia, 2008) specified the duration of NP, which may be of importance if patients with acute NP hold their neck posture in erect position as compared to those without NP (Clark et al., 1979). Nor did these studies consider the position of the head and thorax, which could help identify the inter-relationship between spinal segments and their biomechanical load.

Another adult study found neck and thoracic angular measures were associated with NP in sitting in 60 participants with at least a six month history of NP (Lau et al., 2010). After adjustment for age and sex, participants with a less flexed thoracic spine had greater odds of NP (OR 1.37, 95% CI 1.11 – 1.68), whilst participants with less neck flexion were at decreased odds of NP (OR 0.86, 95% CI 0.75 -1.0) (Lau et al., 2010). Neither neck nor thoracic angular measures were associated with severity of pain as measured by a numeric pain rating scale or neck disability as measured by the Northwick Park NP Questionnaire (Lau et al., 2010). However the study did not control for height and weight or other psychosocial factors that may confound the relationship between neck posture and NP. Furthermore this study did not explore the intersegmental relationship between the neck and thorax or evaluate head tilt, which may be of importance. In a study conducted in standing, NP was associated with an angular measure of neck tilt (angle from the horizontal tough C7 to the tragus) (Silva et al., 2009). Participants with NP were found to have less neck tilt (more neck flexion) (NP mean (SD): 45° (7°); no NP mean (SD): 49° (7°) (Silva et al., 2009). After dividing the population into younger (under the age of 50 years) and older participants (over the age of 50), only younger participants with NP were found to have less neck tilt (more neck flexion) compared to young pain free participants (NP mean (SD): 46° (6.7°); no NP mean (SD): 59° (5.9°)) (Silva et al., 2009). No association between head tilt position and NP was found. This study did not include any measures of the thoracic spine, or evaluate an intersegmental relationship between the neck and head. Whilst the study did match the control group by sex and age, it did not adjust for height, weight and other psychosocial factors that could confound the relationship between neck posture and NP and potentially affect the results.

In a study of 88 adults neck posture was visually categorised into mild, moderate or severe categories of postural deviations from Kendall's (Kendall et al., 1993) 'ideal' posture. There was no relationship between the severity of forward head posture (defined as an anterior deviation of greater than 1 cm at the lobe of the ear from a plumb line) with frequency or severity of NP of an unspecified duration (Griegel-Morris et al., 1992). However no formal measurement from the plumb line was described. Visual categorisation of posture has previously shown to have poor reliability (Silva et al., 2010a) casting doubt on the findings of the study. Similarly when habitual sitting and standing neck posture was referenced to end range positions using a distance measure (habitual posture was calculated as the distance from full retraction divided by the distance from full retraction to full protraction and expressed as a percentage) there was no significant difference between 42 NP subjects and 42 matched controls (NP mean (SD): 48.0% (SD not recorded); no NP mean (SD): 42.2% (SD not recorded)) (Hanten et al.). The authors did not specify the duration of pain or adjust for height or weight. One study included 21 participants with NP that was aggravated by postural loading and relieved by posture modification and had been present for at least three months (Edmondston et al., 2007). There was no significant difference between NP and no NP groups for the angle of tilt at the head (NP mean (SD): 20° (7°); no NP mean (SD): 20° (7°)) or the intersegmental angle from T4 through C7 to the tragus (NP mean (SD): 16° (6°); no NP mean (SD): 16° (5°)) as measured by 3D motion analysis (Edmondston et al., 2007). However a small sample size potentially affected the power of the study.

One small cross sectional field study found flexion of the cervical spine and head measured by 2D video analysis were not different in eight computer workers with NP compared to eight workers without symptoms (NP mean (SD): 61° (6.1°); no NP mean (SD): 57° (6.2°)) (Szeto et al., 2002). In another study 3D video posture analysis measures of 21 subjects with neck and upper limb work related pain were compared to 17 subjects without pain. Those with pain were found to perform a typing task with the neck and head segment in greater flexion with the more flexed position maintained through the one-hour task duration (NP mean (SD): 68° (11°); no NP mean (SD): 64° (12.9°)) (Szeto et al., 2005b). However only females were enrolled in this study and the inclusion of multiple areas of pain in the upper limb and the capture of data over a one hour time frame as compared to a snap shot of time in the former study likely accounts for the differences in findings.

In summary, the link between NP and posture remains unclear. Postural measurement variables, groups of participants and definitions of posture have differed in previous studies, making direct comparison difficult. The between NP and no NP group estimates in those studies with positive findings have been small, casting doubt on their clinical meaning. No previous studies have considered a combination of angular and translational neck measures. Only one study considered NP provoked by sustained postural loading and found there was no difference in habitual posture of the 21 subjects in the symptomatic group as compared to asymptomatic groups (Edmondston et al., 2007).

Table 1.2: *Summary of sagittal photographic studies investigating the relationship between neck pain and posture*

	Study Type	Measures	Position	Age range	Participant numbers	Neck pain definition	Outcome
Ariens et al. (2001a)	Prospective	Angular	At work place	Mean age 35.7, SD 8.5	1334	Regular or prolonged NP in past 12 months	Trend for positive relationship between neck flexion and NP (not statistically significant)
Edmondston et al. (2007)	Cross sectional	Angular	Sitting	20 – 45 years	21 with NP, 22 no NP (matched)	NP aggravated by sustained postural loading/ relieved by postural modification. No movement restriction. NP > 3 months	No difference in habitual posture between NP and no NP groups. Greater variance of habitual posture in the NP group
Griegel-Morris et al. (1992)	Cross sectional	Visual categorisation	Standing	20 – 50 years	88	Derived from own questionnaire	No association between forward head posture with frequency or severity of NP
Grimmer (1996)	Cross sectional	Translational	Sitting	Not reported	427	NP in the last month	No association between NP and 5 subgroups of neck posture when the data was divided into quintiles
Hanten et al. (2000)	Cross sectional	Translational	Sitting and Standing	20 – 60 years	42 with NP; 42 no NP (matched)	Specific diagnosis derived from physiotherapist, chronicity not defined	No significant difference between asymptomatic and NP groups
Lau et al. (2010)	Cross sectional	Angular	Sitting	20 -50 years	15 with NP, 17 no NP	>3 on Northwick Park NP Questionnaire. Chronicity unclear.	Participants with NP had more neck flexion and more upper thoracic flexion.
Oliveira and Silva (2016)	Cross sectional	Angular	Standing	15 – 18 years	35 with NP; 35 no NP	NP present at least once a week in the last 3 months	Participants with NP had significantly less neck flexion than asymptomatic participants
Osmotherly and Attia (2008)	Cross sectional	Angular	Sitting	17 – 60 years	34 computer based workers	Insidious onset NP. Northwick Park NP questionnaire. Chronicity unclear	Correlation between a more flexed cervical spine and NP related disability
Ruivo et al. (2014)	Cross sectional	Angular	Standing	15 – 17 years	275	Regular NP	Participants with NP had significantly more neck flexion than asymptomatic participants
Silva et al. (2009)	Cross sectional	Angular	Standing	33-69 years	40 with NP, 40 no NP	NP non traumatic >6 months	Association between NP and head forward posture in younger (< 50 years) but not older participants
Straker et al. (2008)	Cross sectional	Angular	Sitting	14 years	1470	NP ever, in the last month, today	Posture not predictive of NP ever after controlling for sex
Straker et al. (2009)	Cross sectional	Angular	Sitting	14 years	1470	Prolonged NP	When sex controlled for only lumbar lordosis related to the presence of prolonged NP
Szeto et al. (2002)	Cross sectional	Angular	Sitting at computer	22 -40 years	18 females 8 with NP, 10 no NP	Current neck and shoulder discomfort >2/10. Chronicity unclear	Trend for increased head tilt and neck flexion postures in symptomatic subjects (not statistically significant)
Yip et al. (2008)	Cross sectional	Angular	Standing	29 -42 years	62 22 males, 40 females	Physiotherapy diagnosis of NP. Northwick Park NP Questionnaire.	Participants with NP had greater neck flexion angles. More neck flexion angle correlates with neck disability

SD Standard deviation. NP Neck pain

1.5.4 Clusters of neck posture and their association to neck pain:

Relationships between neck posture and NP could be 'washed out' if there is no consideration of the potential for neck posture clusters. The washout effect, where the findings of one subgroup of participants cancels out the opposite findings in another subgroup has been demonstrated in the context of lumbar posture and prolonged low back pain (Dankaerts et al., 2006). When participants with chronic non-specific low back pain were pooled into one group and compared to asymptomatic patients there was no difference in usual sitting posture. However differences in usual sitting posture were revealed when the chronic non-specific low back pain participants were sub classified. Similarly there was no consistent pattern of differences between singular postural angular measures and back pain variables in the Raine cohort study of 766 14 year olds (Smith et al., 2008a). Subgroups of thoraco-lumbo-pelvic posture were derived using hierarchical (Ward's) followed by nonhierarchical (K-means) cluster analysis of three postural measures. The cluster analysis was able to capture participants with pronounced flexion and extension lumbar curves from a neutral posture. Four clusters were found to exhibit different profiles that corresponded to thoraco-lumbo-pelvic postures previously described in the clinical literature (Kendall et al., 1993, Sahrmann, 2002) and in an X-ray study (Roussouly et al., 2005) and were termed neutral, sway, flat and hyperlordotic. Following subgrouping procedures 'non-neutral' postures in the lumbar spine had a higher risk of back pain in adolescents (Smith et al., 2008a). Thus, valid subgroups of adolescent sagittal thoraco-lumbo-pelvic alignment can be determined successfully from sagittal photographs. Further investigation is warranted using this methodology in the neck.

To date there has been only one study that has used subgrouping procedures when investigating the association between neck posture and NP. An Australian cross-sectional study included 427 participants with no history of neck injury (Grimmer, 1996). Two measurements were taken (i) the vertical distance from C7 to the helix of the ear in two positions (full retraction and habitual sitting posture) and (ii) the horizontal distance from a backboard to C7 and the helix of the ear in two positions (full retraction and habitual sitting posture). The measurements were placed into a formula to generate angles to represent the angular excursion between C7 and the helix of the ear. Frequency distributions of the angular excursion data at the anatomical points were examined and demonstrated a wide variability in the excursion points at C7 and the helix of the ear, likely representing the wide variation in normal habitual posture. Angles were then divided into 5 relatively equal parts. Twenty-five different postural presentations were identified; four groups had extreme excursion occurring at both anatomical points. However, there was no evidence of significant differences in the prevalence of NP experienced in the last month across the 25 groups ($F = 0.80$, $p=.37$). There were a number of potential limitations in the study including the way in which the data was divided, more sophisticated mathematical analysis such as cluster analysis may be a more suitable method to group postural measures. Secondly, the measures used in the study did not examine where the neck was in relation to gravity or other body segments and may miss important attributes of posture. Thirdly there was no attempt to adjust for other factors that could be associated with neck posture or NP and potentially confound the relationship.

1.5.5 Clusters of neck posture as a risk factor to neck pain

One prospective study (Brink et al., 2009) compared the posture of participants whose measures were at the extremes of neck and thoracic angles (as defined as the upper and lower quartiles of neck and thoracic angles, i.e. both upright and flexed postures) to the posture of participants in the two middle quartiles. Ten areas of pain in the upper quadrant were found to be associated with the posture of the "extreme" subgroup. However, the inclusion of multiple areas of pain in the upper quadrant may not provide direct evidence of a link between neck posture and NP, but do suggest that different subgroups of neck and thoracic posture may be important as a risk factor for NP. Further investigation using a longitudinal design study to investigate if neck posture subgroups are a risk factor for the presence of NP is warranted.

1.6 Limitations of the literature

There is a growing burden of NP throughout the world and evidence that adolescent NP is becoming more common (Global Burden of Disease Study, 2015, Hakala et al., 2002). This suggests a rising disease burden for future adults (Hakala et al., 2002). Many factors are reported to be associated with NP, however there is a lack of rigorous longitudinal studies that have measured these factors across multiple physical and psychosocial domains. Without such studies, drawing conclusions about the relationship between neck posture and NP is challenging.

Posture is commonly believed to be a risk factor for NP. Assessment of posture is recommended in the evaluation of NP and models of NP intervention have been based around postural correction (Silva et al., 2010b), including work place interventions (Aas et al., 2011) and school based interventions (Geldhof et al., 2006, Linton et al., 1994). However, the lack of effect from these postural intervention studies is coupled with unconvincing evidence of any relationship between habitual neck posture and NP. This may be due to the methodological shortcomings, which include; small sample size, failure to control for sex or age, failure to differentiate between acute and persistent NP symptoms, failure to match test position to the position that provokes NP and failure to report validity, sensitivity or reliability of measures. Furthermore previous studies have focused on singular postural measures and have not taken into account the relationship of the spinal segments above or below and how they are positioned in relation to gravity, which may miss the broader picture of posture characterisation and the associated biomechanical implications.

Further confusion about the link between NP and posture has been created by authors' drawing conclusions that do not match the reported results. Furthermore studies that have found positive associations between NP and neck posture have reported small effect sizes that may be of little clinical meaning. One possible explanation for this is the effect of washout. To date the possibility of neck posture clusters or sub classifications of NP based on its provoking factors (as previously demonstrated in low back pain (Dankaerts et al., 2006)) have not be fully considered in NP.

1.7 Aims and Significance

The three aims for this thesis were designed to investigate relationships between neck posture and neck pain in a large community based cohort of similarly aged participants, while addressing limitations in previous literature (Section 1.6).

Aim 1 of this study was to determine if clusters of sagittal sitting neck posture could be identified.

Aim 2 of this study was to investigate the association between posture cluster membership and persistent NP, NP that is worse when sitting, and headaches. Given the potential complex relationships between the triad of pain, posture and biopsychosocial factors,

factors such as sex, height, weight, depression, exercise frequency, sitting time and computer use were adjusted for.

Aim 3 utilised a longitudinal design to determine if neck posture clusters in adolescents are predictive of the presence of NP in young adults, after adjusting for biopsychosocial factors.

Posture was assessed using angular and translational measures of the head, neck and thorax. This project could significantly add to the knowledge base of neck posture and it's relationship with NP. It could provide guidance in the management of NP in younger age groups and provide conceptual validity for the efficacy of postural intervention. This was deemed highly important as presently postural interventions and global public health messages are being given seemingly without a sound scientific basis.

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Chapter 2 - Study 1

Neck posture clusters and their association with biopsychosocial factors and neck pain in Australian adolescents

Authors Karen Richards, Darren Beales, Anne Smith, Peter O'Sullivan, Leon Straker

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The specific aims of Study 1 were

(i) To determine if sagittal sitting neck posture subgroups could be identified with cluster modeling in late adolescence that correspond to potential variants described in the literature.

(ii) To profile identified posture clusters based on factors potentially associated with sitting posture (sex, anthropometrics, lifestyle, psychological).

(iii) To investigate the association between identified neck posture clusters and neck pain and headaches.

2.1 Introduction

Neck pain (NP) is the 4th most common health disorder for years lived with disability internationally (Vos et al., 2012). Worldwide the percentage of healthcare resources spent on NP are rapidly increasing (Haldeman et al., 2008). Neck pain is reported in childhood (Stahl et al., 2008), and rises in prevalence throughout adolescence (Hakala et al., 2002, Jeffries et al., 2007, Niemi et al., 1996, Vikat et al., 2000). By 18 years NP prevalence is equivalent to adult levels (Jeffries et al., 2007). Neck pain disorders are more common in females (Fejer et al., 2006b, Cote et al., 2004, Walker-Bone et al., 2004, Hakala et al., 2002, Vikat et al., 2000) and have been associated with many different biopsychosocial factors. Associated anthropometric factors include small height (Poussa et al., 2005). Lifestyle factors include increased computer use (Straker et al., 2007) and increased time spent sitting (Ariens et al., 2001a). Psychological factors include depression(Diepenmaat et al., 2006), poor mental health (Croft et al., 2001, Walker-Bone et al., 2004) and stress/psychological distress (Walker-Bone et al., 2004, Croft et al., 2001). Other factors include co-morbid pain sites such as back pain (Croft et al., 2001, Walker-Bone et al., 2004, Vikat et al., 2000), ill health (Vikat et al., 2000, Croft et al., 2001) and physical factors such as reduced muscle endurance (Lee et al., 2005) and altered spinal posture (Harrison et al., 2004, Lau et al., 2010, Silva et al., 2009, Osmotherly and Attia, 2008, Yip et al., 2008, Brink and Louw, 2013).

Neck posture, particularly in sitting, is considered an important contributing factor to the development and maintenance of NP (Brink and Louw, 2013, Lau et al., 2010, Silva et al., 2009, Osmotherly and Attia, 2008, Yip et al., 2008, Griegel-Morris et al., 1992) and headaches (Watson and Trott, 1993). Consistent with this, neck posture is commonly targeted by clinicians to prevent and reduce NP. Sagittal neck posture in sitting has been previously investigated due to a common clinical belief that a more forward head posture (where the head is anterior to the trunk in the sagittal plane) (Grimmer-Somers et al., 2008, Silva et al., 2009) is associated with NP and headaches (Raine and Twomey, 1997). Forward head posture may increase load on passive cervical structures (joints, ligaments)(Grimmer-Somers et al., 2008, Chaffin, 1973) and on the posterior neck musculature by the increased gravitational moment (Szeto et al., 2005a, Edmondston et al., 2011b) and torque around C7 (Pheasant, 1988). This is manifest by increased extensor muscle activity demonstrated in forward head posture (Caneiro et al., 2010, Szeto et al., 2005b).

While these mechanisms are plausible, the link between neck posture and NP is unclear (Silva et al., 2010b). Some studies report an association between neck posture and NP (Brink et al., 2009, Lau et al., 2010, Osmotherly and Attia, 2008, Yip et al., 2008), others do not (Straker et al., 2008, Straker et al., 2009, Edmondston et al., 2007, Szeto et al., 2002, Griegel-Morris et al., 1992, Hanten et al., 2000). Factors contributing to the discordant findings include use of different angular or translational posture variables, inclusion or exclusion of thoracic measures and upper cervical spine measures/head tilt, whether the neck posture was assessed in sitting or standing, the task during which posture was assessed, definitions of NP, sample size and demographics. This makes direct comparisons between studies difficult.

Another potential reason for the disparity in the literature in determining the association between posture and NP could be the existence of neck posture subgroups. Subgroups of sagittal lumbar spine standing posture have been identified using sagittal photography in an adolescent population (Smith et al., 2008a) and sagittal x-rays in adults (Roussouly et al., 2005). In adolescents, individuals with 'non-neutral' standing lumbar posture had higher odds for back pain (Smith et al., 2008a). In adults non-neutral postures were more commonly associated with symptomatic back pain or degenerative disease (Roussouly et al., 2005). Cluster modeling appears highly suited to the examination of posture subgroups (Smith et al., 2008a), but this approach has not been applied to investigate associations between sagittal neck posture and NP.

The literature supports the supposition of subgroups of sitting neck posture. Forward head posture can occur via a combination of upper thoracic flexion and cervical spine flexion (Darnell, 1983, Grimmer-Somers et al., 2008). Two versions of forward head posture have been described, one with and one without extension of the upper cervical spine (Grimmer, 1996). Alternatively forward head posture may exist in moderate and extreme forms (Grimmer, 1996, Grimmer-Somers et al., 2008). Another possible subgroup could be the opposite extreme of forward head posture, a very upright position with the head held close to the vertical axis (Brink et al., 2009). Although there is a lack of consensus to what constitutes 'neutral' neck posture (Jull, 2008), it is likely that a fourth subgroup exists, between the two posture extremes. Thus, the first aim of this study was to determine if sagittal sitting neck posture subgroups could be identified with cluster modeling in late adolescence, that correspond to potential variants described in the literature. The second aim was to profile identified posture clusters based on factors potentially associated with sitting posture (sex, anthropometrics, lifestyle, psychological). The final aim was to investigate the association between identified neck posture clusters and NP and headaches. Significant insight into the potential association between neck posture and NP could be achieved by applying cluster analysis to neck posture data.

2.2 Methods

2.2.1 Study design:

Cross-sectional study in the Western Australia Pregnancy Cohort (Raine) Study (www.rainestudy.org.au).

2.2.2 Participants:

The Raine Study commenced in 1989, with 2868 children born to 2804 mothers. Ethnicity was predominantly Caucasian. At 17, demographic characteristics of the participating families were similar to the Western Australian population for families with 15-17-year-old children, except for a lower proportion of rural dwelling families and a higher proportion of families dwelling in high socio-economic areas (O'Sullivan et al., 2012).

The 17-year-old follow-up took place between June 2006 and December 2009. Research assistants employed by the Raine study collected the data. Participants (average (standard deviation) age 17.0 (0.2) years) completed a questionnaire that included a description of NP and headache and a variety of psychosocial domains. Participants underwent physical testing for height, weight, and photographic sagittal posture assessment.

Ethical approval was from Curtin University Human Research Ethics Committee (Reference HR 84/2005) and Princess Margaret Hospital Human Research Ethics Committee (Reference 1214EP). Consent was obtained from the participants.

2.2.3 Measures:

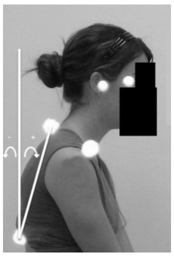
Postural assessment: Postural assessment methods were the same as those used in a prior reliability study that demonstrated reliability and practicality of use in large-scale studies of adolescent posture (Perry, 2008). For consistency photographic reflective markers were placed on bony landmarks on the participant's right side. Landmarks utilised were the outer canthus, tragus and the C7 and T12 spinous processes. A 25cm plumb line was hung from the stool, to calibrate distance and determine vertical. An Olympus camera (Olympus FE-130, Tokyo, Japan) was placed on a tripod 80cm from the floor and 250cm perpendicular to the participant. Right-sided lateral photographs were taken as participants sat on a stool with thighs horizontal and knees flexed to 90 degrees. The standardised instructions used to position the subjects in order obtain the usual posture of the head and neck, were the same as those used in a previously reported reliability study (Perry, 2008). Participants were instructed to "put your hands about 2/3 of the way down your thighs with the palms up, sit like normal and relax, look straight ahead". Markers were digitised using Peak Motus motion analysis system version 8 (Peak Performance technologies, Inc., Centennial CO, USA) software. Measures (Figure 2.1) were selected to best represent the attributes of sagittal posture that relate to the proposed mechanism for NP (Grimmer-Somers et al., 2008) and the components of posture routinely assessed in clinical practice (Silva et al., 2010a).

Inter-rater reliability has been reported as fair to good for these posture variables (Perry, 2008). The reliability of intra-rater re-digitisation for all distance and angular measures used in this study were found to be excellent in this cohort at 14 (Perry, 2008). Radiographic examination is considered the gold standard for postural measurement (Gadotti and Magee, 2008). However its disadvantages include exposure of subjects to ionising radiation and cost, making it unsuitable for use in large population studies. Photographs, whilst not as accurate as x-rays, can detect meaningful classifications of lumbar spine posture that correspond to x-ray classifications (Smith et al., 2008a) and its use is supported in large population studies (Perry, 2008) and is supported for large cohort studies (Perry, 2008).

Anthropometrics: Body mass index (BMI) was calculated from height and weight measures using standard procedures.

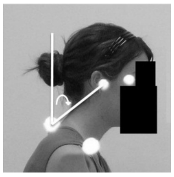
Lifestyle Factors: For physical activity participants were asked; "Outside school, Technical and Further Education (TAFE), or work hours how often do you usually exercise in your free time, so much that you get out of breath or sweat (Once a month or less/Once a week/2-3 times a week/4-6 times a week/Every day)?". For sedentary behaviour participants were asked about computer use and time spent sitting. For computer use they were asked; "On average, how many hours per day do you usually use a computer (e.g. for school/work, games, internet) on a weekday (not at all/less than 1 hour/about 1-2 hours/about 2-4 hours/more than 4 hours)?" Time spent sitting was taken from the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003); "During the last 7 days, how much time did you spend sitting on a weekday (weekend day)?", from these responses a weighted sum variable was calculated representing total hours sitting per week.

Figure 2.1: *Angular and distance measures describing sitting neck posture alignment*



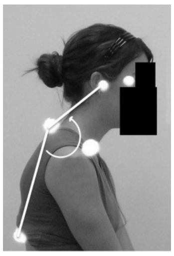
Thoracic Flexion

The angle between the vertical line through T12 and the line fromT12 to C7



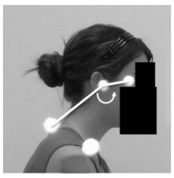
Neck Flexion

The angle from the vertical line through C7 and the line from C7 to the tragus



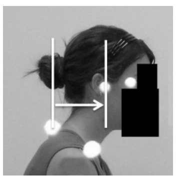
Cervicothoracic Angle

The angle between the line from C7 to the tragus and the line from C7 to T12



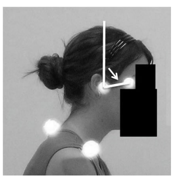
Craniocervical Angle

The angle between the line from the tragus and the canthus and the line from the line of the tragus to C7



Head Displacement

The horizontal distance between C7 and the tragus



Head flexion

The angle between the vertical line through the tragus and the line from the tragus to the canthus

Psychological Factors: Depressed mood was assessed using the 20-item Beck Depression Inventory for Youth (BDI-Y) (Beck et al., 2001). Participants were asked to rate the frequency of their symptoms over the past 2 weeks using a scale of 0 (never) to 3 (always). Responses were summed to produce a total score ranging from 0-60. The BDI-Y has good reliability (Beck et al., 2001). Scores were categorised into a binary variable of 'no or minimal depression' versus 'mild, moderate or severe depression' (Groth-Marnat, 2009).

Neck pain and headache: Participants were asked to look at a picture depicting NP as pain in the neck and upper trapezius region and to answer the follow questions, "Have you ever had neck/shoulder pain (yes or no)?", "Has your neck/shoulder pain lasted more than 3 months continuously (it hurt more or less every day) (yes or no)?", "Has your neck/shoulder pain ever lasted for more than 3 months off and on (it hurt at least once a week but not every day)?" and "Has sitting ever made your neck/shoulder pain worse (yes or no)?". These questions have been adapted from the Nordic questionnaire, which has established validity and reliability (Kuorinka et al., 1987). Positive responses from the first three of these questions were converted into a new variable, presence of persistent NP (PNP), to examine NP of recurrent and prolonged nature. For headaches participants were asked; "Do you have now, or have you had in the past, any of the following health professional diagnosed medical conditions or health problems - migraine or severe headache (yes or no)".

2.2.4 Analysis:

Initial data screening was conducted using boxplots and identified 20 outliers (values 1.5 times the interquartile range). Of these, four participants' photographs were unusable due to quality issues. For the remaining 16 subjects an error was found in the digitisation of two markers used to form the distance calibration. This meant that when this data was used to normalise the scale from those participants the distance measure (i.e. head displacement) was incorrect. Correcting the digitisation of the markers on the distance calibration device meant a correct scaling factor was applied to head displacement measures.

Prior to clustering, the correlation matrix was examined to identify unduly high correlations between posture variables that might result in over-representation in the cluster solutions (Hair et al., 1998). A two-step cluster analysis was performed using standardised (z-scores) posture measures. A hierarchical technique, Wards linkage, was used to derive the number of clusters and their cluster centres, followed by the non-hierarchical, iterative technique of K-Means cluster analysis using the cluster seeds generated from the Wards linkage solution.

Validity of the cluster solution was assessed in three ways. Firstly, it is recommended that the determination of an optimal cluster solution be performed in conjunction with consideration for the interpretability and theoretical meaning of the generated clusters (Hair et al., 1998). Determination of the number of clusters to be estimated was guided by prior literature regarding subgroups of neck posture and the degree to which estimated subgroups corresponded to these. As prior literature suggested that there may be, in addition to a 'neutral' head posture, two different forward head postures (with and without upward head tilt) (Darnell, 1983, Grimmer-Somers et al., 2008), a 3-cluster solution was estimated. Additionally, given the potential of a very upright posture (Brink et al., 2009), a 4-cluster solution was estimated. Clusters from 3- and 4-cluster solutions were compared to posture sub-groups previously described in the literature, and photographs of subjects with values near the centroid of the clusters were examined to interpret their potential clinical relevance. Secondly, split-half sampling of the final 4-cluster solution was conducted. Thirdly, criterion validity of the 4-cluster solution was evaluated by examining profiles across variables not used to form the clusters that had theoretical support for variation across clusters.

Profiles of clusters across variables of interest were assessed using logistic regression (binary variables), ordinal logistic regression (ordinal variables) or linear regression (continuous variables), adjusting for sex due to sex differences across clusters. Sex interactions with profile variables were also assessed to investigate whether patterns of cluster difference varied by sex. Brant test was used to check the proportional odds assumption for ordinal logistic regression. Multivariable logistic regression was used to estimate associations between NP, headache and posture clusters adjusting for the potential confounding variables.

Analysis was performed with Stata version 13 for Mac (StataCorp LP, College Station, Texas, USA). Statistical significance was set at $\alpha=0.05$.

2.3 Results

Of the 1475 subjects in the 17-year-old follow-up, 1123 underwent physical examination including height, weight and posture measures. Following data inspection and cleaning, 1108 participants had complete posture measures available for clustering.

Cluster analysis:

Following conversion of postural data into standardised z-scores, neck flexion and head flexion had a strong negative correlation (r = -0.73). To avoid over-representation in the cluster solution, head flexion was not used as it had been shown to have lower interclass correlation for consistency and absolute agreement compared to neck flexion (Perry, 2008).

Ward's linkage analysis determined the cluster centres of the 5 remaining postural measures (thoracic flexion, neck flexion, cervicothoracic angle, craniocervical angle and head displacement). Examination of the agglomeration schedule and stopping rules (Calinski–Harabasz pseudo_F index and Duda–Hart index) provided most support for the 3- or 4-cluster solutions. Therefore, subsequent K-means cluster analysis estimated both 3- and 4-cluster solutions.

The 4-cluster solution split one large cluster from the 3-cluster solution into two. These new clusters exhibited similar profiles, however on photographic inspection one group demonstrated less thoracic flexion and appeared to sit closer to end range thoracic extension compared to the subgroup it had split from. This biomechanical difference was deemed to be of potential clinical importance, as previous research has demonstrated subjects at extremes of range were at greater risk of NP (Brink et al., 2009). Therefore the 4-cluster solution was chosen as the most supported by the data and clinical relevance. Split-half sampling confirmed very similar 4-cluster solutions.

2.3.2 Clusters Descriptions:

Table 2.1 presents cluster postural measures.

Cluster 1 (n=311, 28%, 'upright') was characterised by the least thoracic flexion and neck flexion of all clusters. There was a small cervicothoracic angle and the craniocervical angle was the smallest of all clusters (i.e. less upwards head tilt). The head was displaced the smallest distance forwards compared to all other clusters.

Cluster 2 (n=265, 24%, intermediate) demonstrated a similar pattern of characteristics as Cluster 1, but had greater thoracic flexion. When considering the position of the neck on the thorax, the cervicothoracic angle was greatest of all the clusters indicating this subgroup was the least flexed. There was less neck flexion, less forward head displacement and slightly smaller craniocervical angle than the overall mean.

Cluster 3 (n=178, 16%, slumped thorax/forward head) was characterised by the most thoracic flexion and the most neck flexion of all clusters. The head was displaced the greatest distance forwards and the craniocervical angle was greater than the other clusters (ie tilting the head upwards).

Cluster 4 (n=354, 32%, erect thorax/forward head) was characterised by slightly less thoracic flexion than the population mean (but more thoracic flexion than Cluster 1) and more neck flexion than the group mean. This cluster had the smallest cervicothoracic angle. The head was displaced forwards (more than Cluster 1 and 2 and a similar distance to Cluster 3) with a slightly increased craniocervical angle (i.e. tilting the head upwards).

2.3.3 Cluster characterisation:

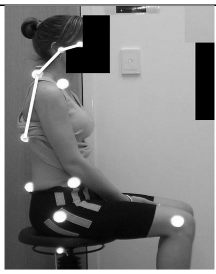
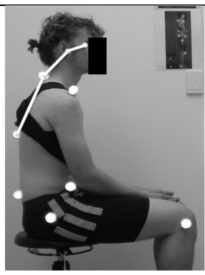
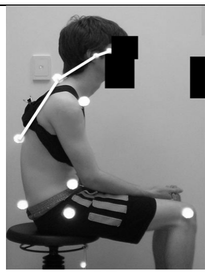
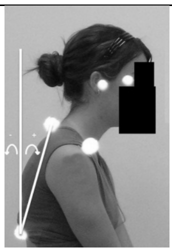
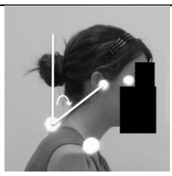
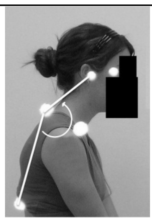
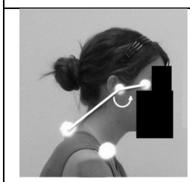
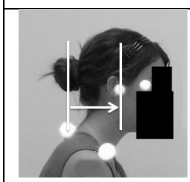
Clusters 1 (upright) and 4 (erect thorax/forward head) had higher proportions of females (Table 2.3, p<.001). Subsequent analyses were adjusted for sex, and the absence of sex interactions was confirmed for all analyses (i.e. no significantly different patterns of difference across clusters in male versus female participants).

Anthropometrics: Cluster 1 (upright) was significantly taller than the other clusters (Table 2.3, p=.011). Cluster 4 (erect thorax/forward head) and Cluster 3 (slumped thorax/forward head) were significantly heavier than Cluster 1 (upright) and Cluster 2 (intermediate) (p<.001). The same association was seen between cluster membership and BMI (Table 2.3).

Lifestyle Factors: Cluster 1 exercised more than the other clusters (p= <.001) (Table 2.3). There were no differences between clusters for the amount of time spent sitting (p=.452) or using the computer (on weekdays) (p=.356).

Psychological Factors: Two hundred and eighty two participants (23%) were classified as having mild or more depression with the BDI-Y (Table 2.2). After adjusting for sex, Cluster 3 (slumped thorax/forward head) had greater odds for depression (p=.047, Table 2.3).

Table 2.1: *Mean (standard deviation) postural measures for each cluster with example participants from each cluster*

Postural Measures	Cluster 1 (n=311): Upright	Cluster 2 (n=265): Intermediate	Cluster 3 (n=178): Slumped thorax/ forward head	Cluster 4 (n=354): Erect thorax/ forward head
				
 Thoracic Flexion	↓ 10.4° (4.0°)	↑ 23.4° (5.1°)	↑↑ 30.0° (5.3°)	↓ 14.7° (4.6°)
 Neck Flexion	↓↓ 41.0° (3.9°)	↓ 44.3° (4.4)	↑↑ 56.6° (5.7°)	↑ 50.2° (4.0°)
 Cervicothoracic Angle	↓ 149.3° (4.4°)	↑↑ 159.1° (5.2°)	↑ 153.4° (6.1°)	↓ 144.5° (4.4°)
 Craniocervical Angle	↓↓ 149.1° (7.4°)	↓ 154.7° (7.5°)	↑↑ 167.1° (9.3°)	↑ 161.1° (8.1°)
 Head Displacement	↓↓ 82.8mm (10.6mm)	↓↓ 83.3mm (11.3mm)	↑↑ 100.3mm (14.2mm)	↑↑ 96.5mm (12.6mm)

↓↓ Decreased compared to the sample mean. ↓ Mildly decreased compared to sample mean. ↑↑ Increased compared to sample mean. ↑ Mildly increased compared to sample mean

***Neck Pain and Headache**:* Two hundred and nineteen participants (22%) reported PNP (Table 2.2), with 141 (64%) being female. After adjusting for sex, there was no difference between the clusters and the odds of PNP (p=.773, Table 2.4). To determine if any association was masked by other variables shown to be different between clusters further adjustment for sex, height, weight, exercise frequency and depression was undertaken. There was still no significant difference between the clusters and the presence of PNP following this (p=.741). One hundred and forty participants (14%) reported NP worse with sitting (Table 2.2). After adjusting for sex, or a multivariable model of sex, height, weight, exercise frequency and depression the odds of NP made worse by sitting did not differ between clusters (p=.150 and p=.246 respectively, Table 2.4).

Ninety six participants (8.8%) reported headaches (Table 2.2), with 51 (53%) being female. After adjusting for sex, or a multivariable model of sex, height, weight, exercise frequency and depression no significant difference was found between clusters and headaches (p=.563 and p=.450 respectively, Table 2.4).

***Table 2.2:** Descriptive statistics of study measures, by sex and overall*

	Females (n=548)	Males (n=560)	Overall (n=1108)
Postural measures (mean, SD)			
Thoracic flexion (^{0})	14(7)	22(9)	18 (8)
Cervicothoracic angle (^{0})	147(6)	154(7)	151 (7)
Neck Flexion (^{0})	47(6)	47(8)	47 (7)
Craniocervical angle (^{0})	157(11)	157(10)	157 (10)
Head flexion (^{0})	70(8)	70(8)	70(8)
Head displacement (mm)	87(13)	92(15)	90 (14)
Physical factors (mean, SD)			
Height (cm)	166(6)	178(7)	172(9)
Weight (kg)[a]	63(12)	72(14)	67(14)
Body Mass Index (kgm^{-2})[a]	23(4)	23(4)	23(4)
Lifestyle factors			
Sitting time (hrs/week: mean, SD)[b]	42.0 (15.7)	40.5 (16.5)	41.2 (16.1)
Exercise frequency (median, IQR)[c]	1 (0-3)	2 (1-3)	2 (1-3)
Weekday computer use (median, IQR)[c]	2 (1-3)	2 (2-3)	2(1-3)
Psychological factors			
Becks Depression Inventory (N(%) mild or more)[d]	161(29)	80(14)	282(23)
Neck Pain and headache			
Persistent neck pain (N(%))[e]	141(28)	78(16)	219(22)
Neck pain worse with sitting (N(%))[f]	97(19)	43(9)	140(14)
Headache (N(%))[g]	51(9)	45(8)	96(9)

SD standard deviation. IQR Interquartile range. [a] data missing for 1 case. [b] data missing for 149 cases. [c] data presented for participants who exercised more than once a week; data missing for 152 cases. [d] data presented for participants who used the computer >5 hours per week; data missing for 31 cases. [e] data missing for 133 cases. [f] data missing for 124 cases. [g] data missing for 30 cases

Table 2.3: *Profiles of anthropometric, lifestyle and psychological factors across clusters and sex-adjusted cluster differences*

	Cluster 1 (Upright) (n=311)	**Cluster 2** (Intermediate) (n=265)	**Cluster 3** (Slumped thorax/ forward head) (n=178)	**Cluster 4** (Erect thorax/ forward head) (n=354)	**p**
Females (N(%))	213 (68.5)	55 (20.8)	44 (24.7)	236 (66.7)	<.001
Anthropometric factors					
Height (cm)					
Females (mean (SD))	167 (6)	165 (6)	165 (6)	165 (7)	
Males (mean (SD))	179 (7)	178 (8)	177 (8)	178 (6)	
Sex-adjusted differences (95% CI)	REF	-1 (-2,0)	-2 (-3,-1)	-1 (-2,0)	.011
Weight (kg)					
Females (mean (SD))	60.1 (8.7)	59.7 (9.8)	68.4 (17.8)	64.7 (13.4)	
Males (mean (SD))	69.2 (9.6)	68.8 (10.7)	73.8 (17.8)	76.3 (14.7)	
Sex-adjusted differences (95% CI)	REF	-0.6 (-2.9,1.6)	5.3 (2.9,7.8)	5.4 (3.5,7.3)	<.001
Body Mass Index (kgm^{-2})					
Females (mean (SD))	21.6 (2.9)	21.8 (3.4)	25.2 (6.2)	23.6 (4.6)	
Males (mean (SD))	21.5 (3.0)	21.6 (3.0)	23.4 (5.2)	23.9 (4.0)	
Sex-adjusted differences (95% CI)	REF	0.2 (-0.5,0.9)	2.4 (1.6,3.1)	2.2 (1.6,2.8)	<.001
Lifestyle factors					
Sitting time (hrs/week)					
Females (mean (SD))	41.2 (15.4)	42.2 (15.8)	44.7 (16.8)	42.5 (15.8)	
Males (mean (SD))	40.4 (14.4)	39.7 (15.9)	39.3 (17.7)	43.5 (18.1)	
Sex-adjusted differences (95% CI)	REF	-0.2 (-3.2,2.9)	0.3 (-3.1,3.7)	1.8 (-0.8,4.5)	.452
Exercise frequency (median, IQR)					
Females (median (IQR))	2 (1,2)	1 (0,2)	2 (1,2)	1 (0,2)	
Males (median (IQR))	2 (2,3)	2 (2,3)	2 (1,2)	2 (1,3)	
Sex-adjusted OR* (95% CI)	REF	0.70 (0.50,0.99)	0.53 (0.36,0.77)	0.56 (0.42,0.75)	<.001
Weekday computer use (median, IQR)					
Females (median (IQR))	2 (1,3)	3 (2,3)	2 (1,3)	2 (1,3)	
Males (median (IQR))	2 (2,3)	2 (2,3)	3 (2,3)	2 (2,3)	
Sex-adjusted OR[a] (95% CI)	REF	0.94 (0.67,1.32)	1.30 (0.88,1.90)	1.11 (0.83,1.49)	.356
Psychological factors					
Becks Depression Inventory (Mild or more)					
Females (n(%))	53 of 210 (25.2%)	23 of 55 (41.8%)	14 of 42 (33.3%)	68 of 235 (28.9%)	
Males (n(%))	10 of 96 (10.4%)	25 of 199 (12.6%)	27 of 126 (21.4%)	17 of 114 (14.9%)	
Sex-adjusted OR[b] (95% CI)	REF	1.48 (0.93,2.34)	1.99 (1.22,3.24)	1.27 (0.87,1.84)	.047

CI confidence interval. IQR interquartile range. OR odds ratio [a]ordinal logistic regression, OR=odds ratio and is interpreted as the proportional increase in the odds for being in a higher category of physical activity/computer use than lower categories combined. [b]binary logistic regression, OR=odds ratio and is interpreted as the proportional increase in the odds for being depressed/anxious.

Table 2.4: *Profiles of neck pain and headache across clusters and adjusted cluster differences*

	Cluster 1 (Upright)	Cluster 2 (Intermediate)	Cluster 3 (Slumped thorax/ forward head)	Cluster 4 (Erect thorax/ forward head)	p
Persistent neck pain					
Females (n(%))	58 of 199 (29.2%)	14 of 48 (29.2%)	8 of 40 (20.0%)	59 of 213 (27.7%)	
Males (n(%))	16 of 87 (18.4%)	29 of 182 (15.9%)	17 of 108 (15.7%)	16 of 98 (16.3%)	
Model 1 OR[a,b] (95% CI)	REF	0.89 (0.56,1.41)	0.75 (0.44,1.28)	0.92 (0.63,1.33)	.773
Model 2 OR[a,b] (95% CI)	REF	0.84 (0.52,1.35)	0.74 (0.42,1.29)	0.89 (0.60,1.33)	.741
Neck pain worse with sitting					
Females (n(%))	33 of 199 (16.6%)	8 of 48 (16.7%)	7 of 40 (17.5%)	485 of 213 (22.5%)	
Males (n(%))	8 of 87 (9.2%)	18 of 181 (9.9%)	5 of 108 (4.6%)	12 of 98 (12.2%)	
Model 1 OR[a,b] (95% CI)	REF	1.12 (0.63,1.98)	0.73 (0.36,1.47)	1.45 (0.93,2.24)	.150
Model 2 OR[a,b] (95% CI)	REF	1.13 (0.64,2.02)	0.74 (0.36,1.52)	1.38 (0.87,2.19)	.262
Headache					
Females (n(%))	25 of 212 (11.8%)	5 of 55 (9.1%)	3 of 43 (7.0%)	18 of 232 (7.8%)	
Males (n(%))	6 of 95 (6.3%)	15 of 200 (7.5%)	15 of 127 (11.8%)	9 of 114 (7.9%)	
Model 1 OR[a,b] (95% CI)	REF	0.81 (0.43,1.53)	1.13 (0.59,2.15)	0.76 (0.44,1.30)	.563
Model 2 OR[a,c] (95% CI)	REF	0.83 (0.43,1.63)	0.82 (0.38,1.73)	0.61 (0.33,1.11)	.450

CI confidence interval. OR odds ratio. Ref reference category. [a]binary logistic regression, OR=odds ratio and is interpreted as the proportional increase in the odds for being depressed/anxious. [b]adjusted for sex. [c]adjusted for sex, height, weight, exercise frequency and depression

2.4 Discussion

Cluster analysis identified four subgroups of sitting neck posture. All were well characterised by multiple measures and their validity supported by previous research. Other strengths included utilisation of a large, community-based cohort of similar age and consideration of differences in profiles of biopsychosocial factors.

2.4.1 Sitting neck posture clusters:

Previous research has described forward head posture as a posture variant (Berthonnaud et al., 2005, Silva et al., 2010b, Silva et al., 2010a, Grimmer, 1996, Grimmer-Somers et al., 2008, Grimmer, 1997). These results support that it is common for 17-year-olds to hold the head anterior to the trunk in the sagittal plane. Two clusters characterised by a forward head posture were identified (Table 2.1) and were separated by the amount of thoracic flexion. Cluster 3 was characterised by the greatest amount of thoracic flexion of all of the clusters whilst Cluster 4 was characterised by a more erect thorax. The forward head posture of Cluster 3 (slumped thorax/forward head) supports the anecdotal descriptions of forward head posture and a previous study where thoracic flexion in sitting was associated with a forward lean of the neck (Grimmer-Somers et al., 2008, Kuo et al., 2009).

There is no clear prior report of an erect thorax in association with forward head posture in sitting (Cluster 4). This may be explained by the majority of previous studies utilising singular postural measures in the neck and/or not having considered thoracic spine position. One study demonstrated forward head posture in standing was not associated with increased upper or lower thoracic curvature (Raine and Twomey, 1997). Differences in postural control strategies and thoracic position may occur between sitting and standing, potentially accounting for differing results. Distinctly different thoracic flexion in Clusters 3 and 4 supports inclusion of this angle in future studies investigating sitting neck posture.

Another difference between Clusters 3 (slumped thorax/forward head) and 4 (erect thorax/forward head) was a larger craniocervical angle in Cluster 3, indicative of a greater degree of upward head tilt. This is consistent with previous forward head posture descriptions (Darnell, 1983, Kendall et al., 1993) and previous neck posture measurements (Grimmer-Somers et al., 2008, Kuo et al., 2009). A potential role of the head on neck posture is to level the eyes (Grimmer-Somers et al., 2008, Jull, 2008). Cluster 3 (slumped thorax/forward head) aligns to this, with greater thorax flexion but also more upward head tilt and thus a level eye gaze. This contrasts to a study conducted in standing that indicated a more flexed neck was not associated with a concomitant tilt of the head upwards (Raine and Twomey, 1997). The lack of agreement may be explained by the relationships of adjacent segments altering in sitting (Kuo et al., 2009).

In contrast to the forward head posture of Clusters 3 and 4, Cluster 1 (upright) had the most upright sitting posture (Table 2.2). This is consistent with a previous study that found decreased forward lean of the neck was associated with decreased flexion in the lower cervical spine and increased flexion of the upper cervical spine with a downward tilt of the head (Kuo et al., 2009). It makes sense that if both the thorax and neck are less flexed that the head will require less upward tilt to level the eyes, as evidenced by the smaller craniocervical angle in Cluster 1.

Cluster 2 posture (intermediate) is somewhat in the middle of the two extreme postures in this study (Cluster 1 (upright) and Cluster 3 (slumped thorax/forward head)). Although there is little evidence to determine what constitutes a neutral posture (Jull, 2008) the intermediate posture of Cluster 2 appears to be consistent with mid-range position of the neck and thorax with the head in a position where the eye gaze is level.

2.4.2 Posture clusters, sex and anthropometric factors:

Similar to previous findings (Straker et al., 2009, O'Sullivan et al., 2006, Straker et al., 2008, O'Sullivan et al., 2011b) females were more commonly represented in clusters with more upright sitting postures. It is not clear why females sit more upright, but could relate to sex differences in other anthropometric factors and/or social factors related to body image (O'Sullivan et al., 2011b). BMI can influence sitting posture (Mitchell et al., 2008), with a higher BMI associated with more slump in sitting (O'Sullivan et al., 2011b). However neither of these studies considered the neck and head position. Results from this study concur with a prior finding that overweight high school students sit in more neck and thoracic flexion (Brink et al., 2009). This may be a consequence of increased load associated with higher BMI, or comorbid muscle deconditioning making it more difficult to hold more erect postures (Smith et al., 2010).

2.4.3 Posture clusters and psychosocial factors:

Cluster 3 participants (slumped thorax/forward head) had higher odds of depressive symptoms (Table 3), consistent with a previous study in adolescents with chronic non-specific musculoskeletal pain for whom slumped postures were associated with higher levels of anxiety and depression (O'Sullivan et al., 2011a). Of note, slumped lumbar sitting posture was not significantly associated with higher scores of depression measured by the BDI-Y in the Raine cohort at the age of 14 (O'Sullivan et al., 2011b). This difference is likely due to the head and neck position in the current modelling, but only trunk position in the former study. A sharp rise in the prevalence of depression in adolescents following the onset of puberty (Thapar et al., 2012) could indicate depression would be a greater influence at 17 than 14. An association between cluster membership and depression supports the concept of a mind-body relationship although the direction of this relationship is unknown (Wilson and Peper, 2004, Riskind, 1984, O'Sullivan et al., 2011b).

2.4.4 Posture clusters and lifestyle factors:

Cluster 1 participants (upright) were more physically active. Physical activity can relate to greater back muscle endurance, which has an association with upright posture (Campbell et al., 2011, World Health Organisation, 2010). This is consistent with an intervention study showing exercise can facilitate adoption of more upright postures (Lynch et al., 2010).

Computer use did not differ between clusters. Previous studies have found transient changes in neck and head tilt posture with different types of information technology used (Briggs et al., 2004). Higher computer use was associated with increased head flexion and neck flexion in males but not females in the Raine cohort at 14 (Straker et al., 2007). Although the former only used singular postural measures, results from this study do appear contrary, as there was no increased computer use in the two forward head posture clusters. Increased computer use, mobile touch screen tablets and smart phone devices since this study was undertaken may mean exposure time has increased and may be relevant to neck posture in adolescents now.

2.4.5 Posture clusters and pain:

There is a strong clinical and societal belief that neck posture is a significant factor associated with NP (Cho et al., 2003). There is some supporting evidence for this view (Lau et al., 2010, Osmotherly and Attia, 2008), whilst other research refutes it (Straker et al., 2008, Straker et al., 2009, Edmondston et al., 2007, Szeto et al., 2002, Hanten et al., 2000). The four neck posture clusters were not associated with PNP or NP made worse by sitting (Table 2.4), despite accounting for limitations in prior research including use of well-defined measures of posture and good characterisation of pain. This study specified that subjects with 3 months of recurrent or prolonged NP were included for analysis, whereas previous studies have not specified the duration of NP (Osmotherly and Attia, 2008, Lau et al., 2010, Hanten et al., 2000). This study also considered NP more specific to the task of sitting, to align with the test position used in an attempt to replicate clinical practice of matching aggravating activities to specific objective findings. To our knowledge no previous research has detailed potential relationships between neck posture and NP that is worse in sitting.

Previous studies indicating an association between neck posture and NP have drawn participants from clinical populations (Hanten et al., 2000, Lau et al., 2010) or workplaces that involve prolonged computer use, an occupational task reported to link with NP perhaps as consequence of the prolonged neck flexion postures adopted (Osmotherly and Attia, 2008). Smaller, specialised samples may misrepresent associations in the general population.

The current results do not support the commonly held clinical and societal belief that NP is related to spinal posture. This is consistent with findings from systematic reviews that the relationship between NP and posture is weak (Brink and Louw, 2013, Silva et al., 2010b). In contrast previous studies report that factors such as genetics (Stahl et al., 2013), female sex (Cote et al., 2004, Fejer et al., 2006b, Hakala et al., 2002, Walker-Bone et al., 2004, Vikat et al., 2000), depressed mood (Walker-Bone et al., 2004), stress (Diepenmaat et al., 2006) and sleep patterns (Auvinen et al., 2010) are associated with NP. This suggests that NP is associated with changes in pain regulatory mechanisms rather than biomechanics. This supports calls to consider and manage NP from a broader biopsychosocial perspective.

There was no difference in the odds of headaches across the 4 clusters, but the definition of headache used in this study was broad. A previous study found neither cervicogenic headache nor migraine was associated with head and neck posture (Zito et al., 2006). Most previous studies looking for a link between neck posture and headaches have focused on cervicogenic headache (Watson and Trott, 1993) or tension headache groups (Fernandez-de-las-Penas et al., 2006, Fernandez-de-las-Penas et al., 2007). Even when considering headache type separately, results are contradictory, with some studies reporting an association between posture and headaches (Watson and Trott, 1993, Fernandez-de-las-Penas et al., 2006) while others do not (Zito et al., 2006, Fernandez-de-las-Penas et al., 2007). These studies used single posture angle measures. More research is warranted using posture clusters and clearly defined headache groups (thus avoiding any washout effect from subgroups of neck posture, or subgroups of headaches).

While there was not a cross-sectional association between posture clusters and NP, prospective examination of the effect of cluster membership on future episodes of NP is worth consideration. Flexed neck posture was not associated with incident NP over three years in one large prospective study of workers in a wide range of work roles across 34 work places (Ariens et al., 2001a). The lack of association observed maybe due to limitations of analysis being performed on mean values from subsamples of the workers at each workplace, rather than at an individual level.

2.4.6 Study limitations:

Posture clusters and experience of pain were not associated in this study. The adolescent age of the subjects limits the extrapolation of results to adults. Furthermore participants in this study were primarily Caucasian Australians. Associations between posture, anthropometric measures, psychological factors, lifestyle factors and NP may be different in populations from other countries or ethnicity. Assessment of standardised posture with 2D photography cannot capture the complex interactions of intersegmental translation and rotation that may be measured by x-ray assessment (Gadotti and Magee, 2008). Another limitation is that photographs represent only in a 'snapshot of time' and cannot reflect changes in posture that occur over time which may affect potential relationships between sitting posture and NP. Complex interactions between sitting posture, sitting task, pattern of breaks and other contributing factors were not captured. While lumbar spine posture was not included in the modelling we acknowledge that it may be important.

2.5 Conclusion

This study identified 4 neck posture subgroups in sitting. The results support previous findings that sitting posture is associated with different dimensions including exercise frequency, depression and BMI (Brink et al., 2009). Despite strong support for the existence of neck posture subgroups, they were not associated with PNP, NP in sitting or headaches in 17-year-olds. This raises questions regarding the efficacy of generic postural advice for adolescents with and without NP.

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Chapter 3 – Study 2

Are neck posture clusters and biopsychosocial factors in late adolescence a risk factor for the presence of neck pain in young adults?

Authors Karen Richards, Darren Beales, Anne Smith, Peter O'Sullivan, Leon Straker

The specific aims of Study 2 were

(i) To determine the prevalence of neck pain in young Australian adults aged 22 years

(ii) To determine if clusters of sitting neck posture identified at 17 years in the cohort were risk factors for the presence of neck pain at 22 years, independent of other identified risk factors.

3.1 Introduction

The problem of neck pain (NP) is presently ranked the 4th highest disorder in the world for numbers of years lived with disability (Global Burden of Disease Study, 2015). Neck pain often originates in childhood (Stahl et al., 2008) with prevalence reported to rise through adolescence, peak in middle age and decline thereafter (Hogg-Johnson et al., 2009). Neck pain is considered a complex, multifactorial condition with a number of different risk factors. These include: female gender (Cote et al., 2004, Niemi et al., 1996, Croft et al., 2001, Siivola et al., 2004) anthropometric factors such as small height (Poussa et al., 2005), psychological factors such as psychological distress or poorer mental health (Walker-Bone et al., 2004, Croft et al., 2001), pain features like a past history of NP (Croft et al., 2001), lower levels of exercise participation (Myrtveit et al., 2014, Siivola et al., 2004, van den Heuvel et al., 2005) and occupational factors such as computer use (Cote et al., 2009).

There is a general assumption amongst society and health care professionals that posture that involves more flexion at the neck or "forward head posture" is both associated with and a risk factor for NP (McAviney et al., 2005). It is hypothesised the biomechanical load associated with increased gravitational moment (Szeto et al., 2005a, Edmondston et al., 2011b), increased torque at C7 (Pheasant, 1988) and altered muscle activation of cervical extensors (Burgess-Limerick et al., 1999, Straker et al., 1997) may perpetuate pain from articular and myofascial structures. However, two systematic reviews of cross-sectional studies challenge this assumption, reporting that current evidence does not support differences in sagittal spinal alignment between those with or without NP (Silva et al., 2010b, Christensen and Hartvigsen, 2008). Limitations in previous studies have included partial characterisation of posture often with singular measures of neck posture without considering the influence of thorax and head position (Hanten et al., 1991, Silva et al., 2009) and lack of control for other factors potentially associated with NP (Silva et al., 2010b). A recent cross-sectional study was designed to over come these limitations (Richards et al., 2016) (Chapter 2 of the thesis). It characterised sagittal neck posture using a composite of 5 posture measures and identified 4 separate sub-groups of sitting neck posture in 1100 17 year olds (upright (28%), intermediate (24%), slumped thorax/forward head (16%), erect thorax/forward head (32%)) (Richards et al., 2016). When accounting for multiple factors (sex, height, weight, exercise frequency, depression), no association was found between neck posture sub-groups and NP.

Prospective studies investigating posture as a risk factor for NP are scant. Only one prospective study specifically investigating neck posture as a risk for future NP was identified. The study, of 1334 adults without NP in the prior 12 months from across 34 workplaces with a wide range of work settings, did not identify neck flexion (assessed by video recordings) as a risk for increased incident NP over 3 years, even after consideration of time spent in neck flexion and biopsychosocial factors that could confound the relationship (Ariens et al., 2001a). However, it was limited by the analysis being performed at the workplace level rather than individual level, with mean values from a subsample of workers from each workplace used in the association analyses rather than individual data, which may have been the reason for the lack of association observed. Another prospective study found participants whose posture was at the extremes of neck and thoracic angles (in the upper and lower quartiles i.e. both upright and flexed postures) were at increased risk for upper quadrant pain (Brink et al., 2009). As the study by Brink et al. (2009) considered 10 upper quadrant areas rather than NP specifically, it does not provide direct evidence for a link between posture and NP. However, the results suggest that different subgroups or extremes of neck or a combination of neck and thoracic posture may be important as a risk factor for NP. Theoretically, both very upright and very protracted neck postures could contribute to cumulative biomechanical load on the spine, which may in turn sensitise structures and cause pain (Straker et al., 2008). Failure to separate subgroups may result in a wash out effect where the negative effects of one group cancel out the positive effects of another, as has been reported in the lower back (Dankaerts et al., 2006).

Despite NP already being common in adolescence (Hakala et al., 2002) there is a lack of longitudinal studies examining posture along with multiple risk factors for NP in young adults. Using a prospective cohort study design, this study aimed to (i) determine the prevalence of NP in young Australian adults aged 22 years; (ii) determine if clusters of sitting neck posture identified at 17 years in the cohort (Richards et al., 2016) were risk factors for the presence of NP at 22 years, independent of other identified risk factors.

3.2 Methods

3.2.1 Study design:

Longitudinal study of the Western Australia Pregnancy Cohort (Raine) Study (www.rainestudy.org.au).

3.2.2 Participants:

Participants for this study were enrolled in an on-going pregnancy cohort study, the Western Australian Pregnancy cohort (Raine) study (www.rainestudy.org.au) that has focused on a wide range of health issues. The Raine study commenced in 1989 with a predominantly Caucasian cohort of 2868 children who were enrolled around their 18th week of gestation. The participants have been followed up at regular intervals throughout their lives. This study utilised data from two time points, at 17 years of age and 5 years later at 22 years of age. Research assistants employed by the Raine study collected the data at both the 17 and 22 years follow up. The characteristics of the active participants at 22 have been compared with census data collected in 2011 on all similarly aged young adults in Western Australia, showing that the sample remains representative on a range of variables including education level, employment status, income, marital status, number of offspring, hours of work and occupation (Hoogwout et al., 2015).

For collection of data at 17, ethics approval was granted from Curtin University Human Research Ethics Committee (Reference HR 84/2005) and the West Australian Department of Health Ethics Committee (Reference EC05-84.2). For collection of data at 22 ethics approval was granted from Human Research Ethics Committees at the University of Western Australia (Reference RA/4/1/5202) and Curtin University (Reference HR67/2013).

3.2.3 Measures:

Postural assessment: Postural assessment was performed at the 17 year follow up. The methods for collection of posture data in the Raine Study has previously been described (Perry, 2008, Richards et al., 2016). Reflective markers were placed over bony landmarks of the outer canthus, tragus, and the spinous processes of C7 and T12 on the participants' right side. A 25cm plumb line was hung from the stool in order to measure true vertical and calibrate distance measurements. Participants were asked to 'sit like normal and relax' on a stool that was adjusted to the height of their popliteal fossa and 'look straight ahead'. Lateral photographs were taken using an Olympus camera (Olympus FE-130) that was positioned on a tripod 80cm from the floor and 250cm perpendicular from the participant. Six research assistants collected the posture images from the cohort. Marker points were digitised using Peak Motus motion analysis version 8 (Peak Performance technologies, Inc., Centennial CO, USA). Excellent re-digitisation reliability for these variables has been reported (Perry, 2008). Standard measures were calculated as defined in Figure 2.1. Identical or analogous measures have been used in other studies (O'Sullivan et al., 2006, Straker et al., 2009, Straker et al., 2008) and they share components of posture commonly assessed in clinic for patients with NP (Silva et al., 2010b). Inter-rater reliability has been reported as fair to good for these posture variables and their use is recommended for large cohort studies (Perry, 2008).

Derivation of neck posture clusters has been previously described (Richards et al., 2016) (Chapter 2 of the thesis). In brief, sitting neck posture was classified into 4 sub-groups using K-means cluster analysis (Richards et al., 2016). Wards linkage hierarchical technique was used to derive the number of clusters and their cluster centres, followed by the non-hierarchical, iterative technique of K-Means cluster analysis. Validity of the cluster solution was assessed in three ways: (i) clusters generated from cluster solutions were compared to posture sub-groups previously described in the literature, and photographs of subjects with values near the centroid of the clusters were examined to interpret their potential clinical relevance; (ii) split-half sampling of the 4-cluster solution was conducted; and (iii) cluster profiles were examined for criterion validity across variables not used to form the clusters that had some theoretical support for variation across clusters.

Neck Pain: Participants were asked a series of questions about NP that had been adapted from the standardised Nordic questionnaire, for which validity and reliability has been previously reported (Kuorinka et al., 1987). The questions relevant to this study were asked at both the 17 year and 22 year follow ups. Participants were asked to answer "yes or no" to the following questions; "Have you ever had neck pain?", "Has your neck pain ever lasted more than 3 months continuously (it hurt more or less every day)?", "Has your neck pain ever lasted for 3 months on and off (it hurt once a week but not every day)?" In order to examine the effect of prolonged and recurrent NP, a positive response from either of the latter two questions were considered to indicate the presence of persistent neck pain (PNP) at each time point.

Anthropometric factors: Height and weight was measured and BMI was calculated using standard methods.

Psychological factors: The 20-item Beck Disability for Youth (BDI-Y) was used to assess depression at age 17 (Beck et al., 2001). Symptom frequency over the preceding two weeks was rated from 0 (never) to 3 (always). Summing of item scores produces a total score between 0 – 60, higher scores indicate a more depressed mood. Good validity and reliability of BDI-Y has been reported (Beck et al., 2001, Kovacs, 1992). In this study scores were dichotomised into, those with 'no or minimal depression', and those with 'mild, moderate or severe depression' (Groth-Marnat, 2009).

Lifestyle factors: At the age of 17 participants were asked: "Outside school, Technical and Further Education (TAFE) or work hours how often do you exercise in your free time, so much so you get out of breath or sweat; Once a month or less/ Once a week/ 2-3 times a week/ 4-6 times a week/ Every day?". Responses were converted into a dichotomous variable to separate those who undertook exercise once a week or less versus those who exercised more than once a week.

Work Physical Demands: At the age of 22 participants were asked; "Which of the following statements best describes the work that you do in your current job? Sedentary occupation (e.g. secretary- where you spend most of your time sitting); Standing occupation (e.g. shop assistant, security guard - spend most of your time standing/walking but not intense physical effort); Physical work (e.g. plumber, nurse - a job that requires some physical effort including handling of heavy objects and use of tools); Heavy manual work (e.g. bricklayer - a job that involves very vigorous physical activity including handling very heavy objects)". Questions were derived from European prospective investigation into cancer and nutrition physical activity questionnaire for which the validity has been previously reported (Wareham et al., 2002).

3.2.4 Analysis:

The associations between PNP at 22 and covariates of interest at 17 as well as occupation at 22 were initially analysed using chi-squared tests (categorical variables) or linear regression (continuous variables). A series of logistic regression models were assessed; initially univariable logistic regression was used to estimate the unadjusted odds ratios (OR) for PNP referenced to no PNP at 22 for all independent variables. Then, all variables of interest that were significant at the p=.01 level were included in model 1. Variables that remained significant in model 1 were included in model 2 to adjust for possible confounding effects in the association between posture clusters and pain. At this step an interaction test between work physical demands at 22 years and posture clusters was performed to check equivalence of PNP association with posture clusters over different levels of physical demand.

Statistical analysis: Analysis was performed using Stata version 13 for Mac (StataCorp LP, College Station, Texas, USA). Statistical significance was reported as α < 0.05.

3.3 Results

At 17, 1108 of 1726 participants had a complete set of postural measures. At 22, 1234 participated in the study. A total of 686 (321 (46.8%) male and 365 (53.2%) female) participants completed both postural assessment at 17, NP data at 17 and NP data at 22 (58.1%) and were included in subsequent analyses. Participants with missing data on covariates of interest are indicated in Table 3.1.

3.3.1 Prevalence of persistent neck pain at 17 and 22:

At 22, 192 of 686 participants (28.0%) reported PNP, which had risen significantly from 152 of 686 participants (22.0%) with PNP at 17 (p= <.001). Persistent neck pain at 17 years was strongly associated with PNP at 22 years, with a significant increase in odds of PNP at 22 if participants had experienced PNP at 17 years (unadjusted OR = 4.19, 95% confidence interval (CI) 2.86 - 6.12, p <. 001, Table 3.1).

3.3.2 Association of persistent neck pain at 22 with covariates of interest:

Table 3.1 displays the prevalence of PNP at 22 across categorical covariates of interest. In addition to PNP at 17, female sex was strongly associated with PNP at 22, with 129 of 365 females (35.3%) reporting PNP at 22 versus 63 of 321 males (19.7%, Table 3.1). This corresponded to an unadjusted odds ratio for females versus males of 2.24 (95% CI 1.58 – 3.17, p <.001, Table 3.2). Although PNP at 22 was more prevalent in those participants with mild or greater symptoms of depression at 17 (49 of 143, 34.3%) than those without symptoms of depression (141 of 527, 26.8%, Table 3.1), this was not a statistically significant association (univariable OR 1.42, 95% CI 0.96 - 2.12, p=.078, Table 3.2). There was no difference in PNP between those participants reporting exercising more or less than once a week at 17 (Table 3.1 and 3.2). Taller participants were found to have significantly lower odds for PNP at 22 (OR 0.97 per cm increase, 95% CI 0.95 - 0.99, p =.004, Table 3.2). Heavier participants had slightly lower odds for PNP at 22, although this association was not statistically significant (OR 0.99 per kg increase, 95% CI 0.97 to 1.00, p=.055, Table 3.2). There was no association between BMI and PNP at 22 (OR 0.99, 95% CI 0.95 to 1.03, p=.581). There was no evidence that work physical demands at 22 were associated with PNP at 22 (p=.58, Table 3.2).

Table 3.1: *Prevalence of neck pain at 22 by posture cluster membership, and covariates of interest*

	N	PNP at 22 (28.0%)	No PNP at 22	p-value[a]
Posture Clusters				.002
1 (upright)	204	72 (35.3%)	132 (64.7%)	
2 (intermediate)	156	36 (23.1%)	120 (76.9%)	
3 (slumped thorax/forward head)	103	17 (16.5%)	86 (83.5%)	
4 (erect thorax/forward head)	223	67 (30.0%)	156 (70%)	
PNP at 17 years (n(%))				<.001
No	534	112 (21.0%)	422 (79.0%)	
Yes	152	80 (52.6%)	72 (47.4%)	
Sex				<.001
Male	321	63 (19.7%)	258 (81%)	
Female	365	129 (35.3%)	236 (65%)	
Depression[b]				.078
No	527	141 (26.8%)	386 (73.2%)	
Yes (mild or more)	143	49 (34.3%)	94 (65.7%)	
Exercise more than once a week[c]				.436
No	262	77 (29.4%)	185 (70.6%)	
Yes	413	110 (26.6%)	303 (73.3%)	
Occupation type[d]				.575
Sedentary	168	48 (28.6%)	120 (71.4%)	
Standing	205	63 (30.7%)	142 (69.3%)	
Physical	163	40 (24.5%)	123 (75.5%)	
Heavy manual work	33	8 (24.2%)	25 (75.7%)	
Anthropometric factors				
Height (m)		1.70 (0.09)	1.73 (0.09)	.004
Weight (kg)[e]		66.1 (14.3)	67.8 (13.7)	.005
BMI (kg/m^2)[e]		22.7 (4.1)	22.7 (4.2)	.055

[a]Analysed with Chi squared test; [b]missing for 16 cases; [c]missing for 11 cases; [d]missing for 117 cases; [e]missing for 1 case; m = metres; kg = kilogram; BMI = body mass index; kg/m^2= kilogram/metre^2

3.3.3 Association of PNP at age 22 with posture cluster membership:

An initial multivariable model adjusted for covariates with univariable association p<.10 (PNP at 17, sex, height, weight and depression) (Model 1, Table 3.2). This indicated that PNP at 17 and female sex remained independently and significantly associated with the presence of PNP at 22. Thus these covariates were included in the final multivariable model to assess the association of posture cluster membership with PNP at 22 (Model 2, Table 3.2).

In this final multivariable model, the overall test for significance for differences in odds between clusters for the presence of PNP at 22 was not significant (p=.214, Table 3.2).

However, the adjusted estimates of PNP by cluster were highest in Cluster 1 (31.9%) and lowest in Cluster 3 (20.3%), and 28.0% in Cluster 2 and 27.4% in Cluster 4 (Table 3.2). Compared to Cluster 1 (upright), Cluster 3 (slumped thorax/forward head) had decreased odds for the presence of PNP at 22 (OR 0.51, 95% CI 0.27 - 0.97, p=.040, Table 3.2).

An interaction test between posture cluster membership and PNP at 17 (in a model adjusting for sex) did not detect any evidence that the pattern of differences in prevalence of PNP at 22 between the 4 clusters was different in those with versus those without PNP at 17 (p=.546). Similarly, an interaction test between posture cluster membership and workplace demands (in a model adjusting for sex and PNP at 17 years), did not detect evidence that the pattern of differences in the prevalence of PNP at 22 between the 4 clusters differed according to workplace demands (p=.843).

Table 3.2: *Univariable and multivariable logistic regression models for persistent neck pain at 22 years*

	Unadjusted			Model 1[a]			Model 2[b]		
	OR	95%CI	p	OR	95%CI	p	OR	95%CI	p
Clusters									
1	REF		.002	REF			REF		.214
2	0.55	0.34,0.88	.013	.84	0.49,1.44	.537	.81	0.47,1.39	.448
3	0.36	0.2,0.66	.001	.55	0.28,1.05	.071	.51	0.27,0.97	.039
4	0.79	0.52,1.18	.248	.79	0.50,1.22	.294	.79	0.51,1.21	.273
PNP at 17	4.2	2.86,6.12	<.001	3.59	2.42,5.32	<.001	3.78	2.57,5.57	<.001
Female sex	2.24	1.58,3.17	<.001	1.82	1.07,3.11	.026	1.75	1.16,2.65	.008
Height (cm)	0.97	0.95,0.99	.004	1.00	0.98,1.03	.723			
Weight (kg)	0.99	0.97,1.0	.055	1.00	0.98,1.01	.872			
BMI (kg/m^2)	0.99	0.95,1.03	.581						
Depression	1.42	0.96,2.12	.078	1.12	0.72,1.72	.615			
Exercise	0.87	0.62,1.23	.436						
Occupation type									
Sedentary	REF		.58						
Standing	1.1	0.71,1.73	.65						
Physical	0.81	0.5,1.3	.41						
Heavy manual	0.8	0.34,1.9	.61						

[a]Adjusted for covariates with univariable association p<.10; [b]Adjusted for covariates significant in Model 1 at p<.10; CI = confidence interval; cm = centimetres; kg = kilograms; kg/m^2= kg/metre^2

3.4 Discussion

This study investigated neck posture clusters in late adolescence as a potential risk factor for the presence of PNP in young adulthood. The study utilised well-defined measures of sagittal sitting neck posture in a large community-based sample. Neck posture cluster membership was not a risk factor for the presence of PNP after adjusting for other related factors. Ironically, in contrast to popular belief, the cluster with the lowest prevalence of PNP was characterised by a slumped thorax/forward head posture, while the cluster with the highest prevalence of PNP was the upright posture.

3.4.1 PNP Prevalence:

In this study the lifetime prevalence of PNP (i.e. 3 months of prolonged or recurrent NP) increased from 22% at the age of 17 to 28% at 22. This is in keeping with other studies that reported an increase in six month prevalence of NP (defined as at least weekly) from 6% in early adolescence to 26% in late adolescence (Vikat et al., 2000) and from 17% in late adolescence to 28% in young adults (Siivola et al., 2004). The lifetime prevalence of PNP at 17 observed in the current study was in the middle of these previous studies, although cannot be directly compared as previous studies (Siivola et al., 2004, Vikat et al., 2000) used a range of ages over late adolescence whereas this study used a discrete age of 17. Secondly, a prevalence period of six months was considered in previous studies (Siivola et al., 2004, Vikat et al., 2000) rather than lifetime prevalence used in this study. However, the overall prevalence of NP at the age of 22 is similar to that of young adults found in the latter study (Siivola et al., 2004).

3.4.2 Risk Factors from covariate analysis:

Previous PNP: This study found that PNP experienced at the age of 17 was a risk factor for the presence of PNP at 22, with an OR of 3.78. This is consistent with prior studies which have found frequent NP in 15-18 year old adolescents to be significantly associated with a high six-month prevalence of NP in 22-25 year old adults (OR 1.8) (Siivola et al., 2004). The higher odds of PNP in the current study maybe due to differences in the definition of NP, the age range of the participants and the different prevalence period. However, evidence from both studies is consistent that NP in adolescence predicts NP as an adult suggesting that early prevention and management efforts might help reduce NP in adulthood. Potentially sensitisation of spinal structures may be responsible for the increased risk of future NP. The finding that PNP at 17 predicts PNP at 22 is consistent with the literature, which demonstrates the most consistent risk factor for the development of pain is a previous episode of pain (Henschke et al., 2015).

Sex: Analogous with other studies in adolescent and adult populations, this study found a greater prevalence of NP in females than males (Niemi et al., 1996, Hakala et al., 2002, Vikat et al., 2000, Walker-Bone et al., 2004). Female sex was also found to be a risk factor for the presence of PNP with an OR 1.75. The findings are consistent with a study which reported females had an increased risk of weekly NP (OR 1.7) (Siivola et al., 2004), and another study that reported females had an increased risk of NP that lasted for at least one day (OR 1.2) (Croft et al., 2001). A higher prevalence of other areas of musculoskeletal pain in females is also consistently reported, including low back pain (Hoy et al., 2010a) and headaches (Stovner et al., 2006), and some chronic pain disorders are also known to be more common in females than males (Blyth et al., 2001). It has been proposed that physiological, hormonal and psychosocial differences in pain sensitivity or expression between males and females (Hashmi and Davis, 2014), may underpin these differences (Kvachadze et al., 2015).

Anthropometric measures: This study did not find that height at the age of 17 was a risk factor for the presence of PNP at 22. The findings are similar to a previous study that found height in adolescents between the ages of 15 to 18 was not a risk factor for NP between the ages of 22 to 25 (Siivola et al., 2004). One study of 430 children conducted in Finland reported that small height at 11 was a risk factor for the incidence of NP at 22 (OR 0.78, 95% CI 0.62- 0.97) (Poussa et al., 2005). However, the same study also reported that height at 14 was not a risk factor for NP at 22 (OR 0.86, 95% CI: 0.68 – 1.08). Potentially results were confounded by other factors that were not controlled for in the study by Poussa et al. (2005). Likewise, weight was not found to be a risk factor for the presence of PNP in this study and is in-keeping with the finding of the previous study (Poussa et al., 2005) that also found weight at 11 was not a risk factor for NP at 22. BMI was considered as a potential risk factor for NP in another study (Siivola et al., 2004). The result concurs with this study, that higher BMI did not increase the risk of NP.

Psychological factors: This study used BDI-Y, a specific measure for depression and found it was not a risk factor for the presence of PNP at 22. This finding contrasts to other studies that have captured psychological factors such as stress, psychological distress or poor mental health with measures such as the General Health Questionnaire and Short-Form 36 item health questionnaire (SF-36), which were found to be risk factors for NP (Walker-Bone et al., 2004, Croft et al., 2001). Other psychological factors not measured may be more closely linked to NP than depression alone.

Exercise: Exercise frequency at 17 was not a risk factor for the presence of PNP at 22. Other studies have investigated different aspects of exercise including performing upper limb dominated sports (Siivola et al., 2004) and participation in physically demanding sports for more than 10 months a year (van den Heuvel et al., 2005). Both studies found these types of exercise decreased the risk of NP, even after adjustment for sex and mental health or behavioural factors. The nature, intensity and duration of exercise may have different effects on NP and may explain why findings from this study differ.

Occupation type: One strength of this study was the consideration of occupational data. Previous studies have shown that office- and computer-workers had the highest incidence of NP (Cote et al., 2009) and that annual prevalence of NP varied across occupations (Cote et al., 2009). In contrast, cross sectional results in this study indicated that the prevalence of PNP at 22 did not vary across occupational groups classified by physical demands between the four posture clusters at 22.

3.4.3 Posture sub-groups and persistent neck pain:

This study did not find evidence that posture clusters membership at 17 years of age predicted the presence of PNP at 22 years, after adjustment for previous PNP and sex. Two of the clusters considered in this study were characterised by forward head posture. It has been hypothesised that biomechanical load created by the head being more forward of the centre of gravity may lead to a higher prevalence of NP in people with habitual forward head posture (Edmondston et al., 2011b). However, our results do not support this. Although the overall test for posture cluster membership was not statistically significant, there were unexpected differences between groups that are notable in light of these previously hypothesised mechanisms. The cluster with the lowest prevalence of NP was characterised by a slumped thorax/forward head posture, while the cluster with the highest prevalence of NP was the upright posture. Using upright as the reference category, this group was estimated to have higher odds for PNP than the slumped thorax/forward head cluster (OR 0.51, 95% CI 0.27 - 0.97, p= .039). Previous research has identified higher muscle activity of the upper thoracic erector spinae muscles in a thoracic upright posture as compared to a slumped thorax/forward head posture which may expose the cervico-thoracic spine to greater loading through their multi segmental attachments (Caneiro et al., 2010). Alternatively muscle pain of the thoracic erector spinae may be associated with a sustained low force to remain in an extended posture. It is theorised that pain develops as consequence of overload and damage to muscle fibres connected to low threshold motor units (Cote and Hoeger Bement, 2010).

The finding that overall posture cluster membership did not increase the risk of the presence of PNP, echoes previous findings in a workplace study that found neck flexion did not increase the risk of incident NP over three years (Ariens et al., 2001a). The workplace study did not measure the position of the head and thorax, nor account for different subgroups of posture. Despite these methodological differences to the current study, neither study found that head/ neck posture is a risk factor for NP. In contrast, extremes of neck, neck and thoracic angles (Brink et al., 2009) and head flexion (Brink et al., 2015) were reported to be risk factors for 10 areas of upper quadrant pain in adolescent computer users but not specifically NP. Additionally computer related head/ neck posture was associated with more head and neck flexion as compared to habitual sitting posture (Straker et al., 2007). Thereby measurement of posture at a computer used in these studies (Brink et al., 2009, Brink et al., 2015) versus the position used in this study of habitual sitting and looking forward could have significantly influenced the results.

This study did not find flexed and forward head sitting postures to be a risk factor for the presence of PNP, and the results do not support the common belief that slumped, forward head postures are particularly detrimental, given that we observed the lowest odds for PNP in the slumped thorax/forward head group. This is contrary to the common societal belief that sitting up straight is better posture (Boyle, 2016, Shahar, 2013). Furthermore the findings from this study appear to align with findings from studies evaluating school based and workplace interventions that have included posture advice and "proper" positioning, which reported no change in reports of NP as a result of these interventions (Geldhof et al., 2006, Aas et al., 2011, Syazwan et al., 2011). The absence of a longitudinal relationship between neck posture and NP in this large population study, questions the efficacy of generic postural advice to prevent NP. However, it is recognised that population studies may not be sensitive enough to detect how posture relates in each individual circumstance. Combinations of other factors (such as physiological responses to stress, long hours at a computer and inactivity) along with posture may still be important at an individual level.

3.4.4 Strengthens and limitations:

This study has several strengths. The major strength of this study is its longitudinal design. The subgroups of neck posture used in this study were well defined by rigorous cluster modelling procedures utilising measures from the thorax, neck and head. Previous studies have looked at postural measures in isolation (Ariens et al., 2001a, Hanten et al., 1991, Silva et al., 2009). Single postural measures appraise where spinal segments are in relation to the line of gravity. It is likely that the interaction of one body segment to another is important. This study examined both inter-segmental relationships and segmental gravity relationships and thus evaluated spinal posture more comprehensively than previous studies. The clusters corresponded to postural subtypes identified by previous literature (Richards et al., 2016). In previous cross sectional analysis, sex, height, weight, BMI, exercise frequency and depression were found to be associated with posture cluster membership (Richards et al., 2016). It has also been reported that previous NP, occupational type, sex, height, weight, BMI, exercise and depression are risk factors for NP (Croft et al., 2001, Diepenmaat et al., 2006, Ehrmann Feldman et al., 2002, Niemi et al., 1996, Poussa et al., 2005, Cote et al., 2004, Siivola et al., 2004, van den Heuvel et al., 2005) thus were potential confounders of associations between posture and NP. Therefore this study took each of these factors into account.

This study has several potential limitations. Firstly, the photographic method used to capture the posture cluster data can not detect precise anatomical alignment such as intersegmental translation and rotation, which may occur with alterations of posture (Gadotti and Magee, 2013b) and maybe important in the development of NP. Secondly, subjects were asked to sit in a certain manner using standardised instructions in a laboratory setting, which may not be representative of their normal habitual posture. Furthermore the knowledge that posture is being measured may bias participants' postural behaviour (Claus et al., 2016). Thirdly, a photograph only represents a snap shot in time, and may not reflect alterations in spinal posture in different tasks and movement behaviour such as pattern of breaks and the duration of sitting (Claus et al., 2016). One further limitation of this study is that posture was not re-measured at follow-up, thus it is not known if posture cluster membership remained the same. In addition, this study did not take into account muscle activity, which has been previously considered an important factor in postural NP (Lee et al., 2005, Szeto et al., 2005b). Whilst one of the strengths of this study was the collection of occupational data, it may be that other psychosocial workplace factors such as high job demands (i.e. increasing work pressure and increased number of hours spent working) and low co-worker support (Ariens et al., 2001b) not considered in this study may be associated with or be a risk factor for NP. Capture of NP in this study was by self-report with no medical confirmation. However, the questions used to evaluate NP are widely used, demonstrate good reliability (Kuorinka et al., 1987) and are used consistently in epidemiological studies. This study considered lifetime prevalence of NP and defined NP that was persistent by combining questions about NP that was continuously present over three months or present intermittently for three months on and off. There was no attempt to separate the cause of NP, aggravating activities, the severity of NP or levels of impairment in this study that potentially could have been represented differently in each posture subgroup.

3.5 Conclusion

This study found that PNP at 17 years and being female were predictive of the presence of PNP at 22 years, whilst sitting posture at 17 was not. Against common belief, this study found no evidence that forward head postures were risk factors for the presence of PNP. The results question the practice of population based and individual advice to "sit up straight" for the prevention of NP.

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Chapter 4 - Discussion

This discussion is presented in a number of sections. Firstly, a summary of the results related to each of the three aims of the thesis are presented individually, along with a comparison to the previous literature and then a discussion on the significance of the results. Secondly, the strengths, limitations and implications for clinical practice of the three aims are presented collectively. The final section covers the conclusions along with directions for future research.

4.1 Aim 1: Identification and characterisation of posture sub-groups

The first aim of this thesis was to determine if sagittal sitting neck posture subgroups could be identified in 17 year old adolescents. Four subgroups of sitting neck posture were derived from cluster analysis based on their individual characteristics (termed upright, intermediate, slumped thorax/forward head and erect thorax/forward head).

4.1.1 Comparison to the previous literature:

The four sub-groups align to previous descriptions of neck and thoracic spine sitting posture variations (Darnell, 1983, Grimmer, 1997, Visscher et al., 1998). However there were difficulties in comparing the results of the thesis to the previous literature because of the variability in the terms and measures used to describe posture.

Sagittal posture is commonly referenced to a vertical line to appraise spine posture in relation to the line of gravity (Grimmer-Somers et al., 2008). The most commonly cited reference line is that of Kendall et al. (1993) which divides the body into anterior and posterior parts (Grimmer-Somers et al., 2008). Many studies have used reference lines placed through an anatomical marker (e.g. C6, C7 or T1) from which translational measures can be calculated (Aas et al., 2011, Grimmer, 1996, Grimmer, 1997, Hanten et al., 1991, Hanten et al., 2000). Figure 2.1 defines the postural measures used in this thesis.

A single postural measure of flexion or tilt describes where one spinal region is in space. Angular measures between anatomical markers and either a vertical (Straker et al., 2009, Straker et al., 2008, Brink et al., 2015) or a horizontal reference line (Lau et al., 2010, Oliveira and Silva, 2016, Osmotherly and Attia, 2008, Ruivo et al., 2014, Silva et al., 2009, Yip et al., 2008) can be calculated. For the purpose of consistency, in this discussion postural angles that have been referenced to the vertical will be defined as measures of flexion (e.g. neck flexion, head flexion, thoracic flexion) and postural measures that have been referenced to the horizontal will be defined as measures of tilt (e.g. head tilt, neck tilt).

Inter-segmental measures provide a combined measure of two segments and describe the relationship between spinal regions (e.g. the relationship between the neck and the thorax can be measured as the angle from the tragus through C7 to T12).

This thesis is the first of its kind to utilise translational measures as well as singular postural measures and inter-segmental measures at the head, neck and thorax (Figure 2.1, Table 2.1) and also consider how they interact with one another. Using this approach the results can provide a comprehensive characterisation of sagittal sitting neck posture. The majority of other studies have used only single measures (Oliveira and Silva, 2016, Fernandez-de-las-Penas et al., 2006, Yip et al., 2008) or multiple single measures (Osmotherly and Attia, 2008, Grimmer, 1997, Grimmer, 1996, Silva et al., 2009, Lau et al., 2010, Raine and Twomey, 1997, Hanten et al., 1991, Hanten et al., 2000).

Another problematic area in prior literature is the use of the same terminology to describe seemingly different constructs. For example the term 'forward head posture' has been used to describe a translational measurement of the head forwards of a vertical reference line (Grimmer, 1996, Grimmer, 1997, Hanten et al., 1991, Hanten et al., 2000) or an angular measure of neck flexion (Silva et al., 2009, Yip et al., 2008). In this thesis both an angular measure of neck flexion and a translational measure of head displacement were used to define forward head postures.

Despite these challenges, the postural clusters in this thesis were compatible with elements of previous descriptions of upright posture (Visscher et al., 1998) and slumped thorax/forward head posture (Darnell, 1983) detailed in the literature. The erect thorax/forward head posture has not been clearly identified in the literature previously, most likely as other studies have failed to assess the thoracic spine when examining posture. The intermediate posture of this thesis was somewhere in the middle of the two extreme postures (upright and slumped thorax/forward head) although there is little evidence to determine what constitutes a neutral posture, the intermediate posture of Cluster 2 appears to be consistent with mid-range position of the neck and thorax with the head in a position that is not tilted up or down. A more detailed comparison of the Clusters to the previous literature is now presented.

Upright posture (Cluster 1 n = 311 (28%)): A cluster that represented the most upright posture was previously described in a study that measured the amount of horizontal and vertical translation at the upper and lower cervical spine when the head moved from a "corrected" (retracted) position to its habitual posture (Grimmer, 1997). The measures of 427 participants were divided into quintiles. The quintile closest to the retracted position (i.e. the most upright group) displayed characteristics of head slightly tilting upwards with a marked curved cervical lordosis (Grimmer, 1997). The upright posture (Cluster 1) in this thesis had the smallest craniocervical angle (and represented the least upward head tilt) of all four clusters. The differences between this study and the study by Grimmer (1997) were likely to be due to the lack of a specific measure of head tilt by Grimmer (1997).

In a radiology study of 54 healthy subjects, the group classified visually as 'lordotic' exhibited a greater neck tilt (angle from the horizontal through C6 to C1) (mean (SD): 89° (5°)) than the groups classified as 'reversed' (mean (SD): 83° (3°)), and 'straight' (mean (SD): 86° (7°)) (Visscher et al., 1998). The angular measure of the "lordotic" group in the study by Visscher et al. (1998) was a singular measure of neck tilt as compared to the upright cluster of this thesis that included multiple measures at the head, neck and thorax and therefore the lordotic group in the study by Visscher et al. (1998) only represents one of the constructs in the upright posture (Cluster 1) of this thesis.

Due to the spine being a linked structure, the position of the neck segment in space is influenced by the position of the thoracic spine and was measured by the cervicothoracic angle in this thesis. In the upright posture (Table 2.1, Cluster 1) both the thorax and neck were in a more upright position. In this position it makes sense that the head would require less upward tilt to look ahead as evidenced by the small craniocervical angle observed in this thesis (which measured the position of the head in relation to the neck segment below). This spatial relationship between the neck segment and the head was also demonstrated in part by a 2D motion analysis study of 46 healthy adults (Kuo et al., 2009). The study included angular measures of the neck tilt (the angle from the horizontal through T1 to the tragus) and an inter-segmental measure of the neck and head similar to the craniocervical angle in this thesis (the angle from the midpoint between the corner of the mouth and the nasal ala through the tragus to T1). Similar to the findings of this thesis a more upright neck posture was associated with greater downward tilt of the head ($r = -.79$, $p = < .001$) (Kuo et al., 2009). The relationship between the adjacent spinal segments is further supported in a with-in subjects study (Caneiro et al., 2010). Twenty asymptomatic subjects were asked to attain 3 different postures that were measured by a 2D motion tracking system. When sitting in a thoracic upright position the subjects had significantly less head and neck flexion (the angle from the vertical line through C7 to the protuberance of the forehead) than when sitting in neutral (p =.006) and slumped postures (thoracic upright mean (SD): 20° (18°); neutral mean (SD): 28° (21°); slumped mean (SD): 41° (21°) and significantly less forward translation of the head (the horizontal distance between the protuberance of the forehead and C7) than in slumped sitting (thoracic upright mean (SD): -0.9cm (2.1cm slumped mean (SD): 2.6cm (1.9cm)), mirroring the findings of this thesis.

Slumped thorax/forward head posture (Cluster 3 n = 178 (16%)): In the literature there is anecdotal evidence of the most flexed extreme of posture, the slumped thorax/forward head posture (Cluster 3) (Darnell, 1983, Grimmer-Somers et al., 2008). There is general agreement that thoracic flexion is associated with neck flexion and upper cervical spine extension in a slumped thoracic posture (Darnell, 1983, Grimmer-Somers et al., 2008). However previous studies have not included measures of the thoracic spine when investigating forward head posture. Commonly a singular postural measure of neck tilt (Silva et al., 2009, Oliveira and Silva, 2016), or a distance measurement of forward translation of the head (Grimmer, 1996, Grimmer, 1997, Hanten et al., 1991, Hanten et al., 2000) has been used as a measure of forward head posture. The inclusion of the thoracic spine into the clustering procedures in this study separated two forward head postures (slumped thorax/forward head, Cluster 3 and erect thorax/forward head, Cluster 4) (Table 2.1). The slumped thorax/forward head posture in this thesis concurs with an early description of forward head posture (Darnell, 1983) and a previous study of 46 adults where more thoracic flexion (angle at the intersect of the line from L1 to T11 and the line from T1 to T3) in sitting was associated with more neck tilt (the angle from the horizontal through T1 to the tragus) (r = .44, p= <.01) (Kuo et al., 2009). Furthermore the characteristics of more thoracic flexion, more neck flexion and more forward displacement of the head seen in this thesis were also described by Caneiro et al. (2010) when participants were asked to assume a slumped sitting position in a within subjects study design.

Erect thorax/forward head posture (Cluster 4 n = 354 (32%): A second sub-group of forward head posture (erect thorax/forward head, Cluster 4) was found in this thesis. This Cluster was separated from the slumped thorax/forward head posture (Cluster 3) by a lesser amount of thoracic flexion (Table 2.1). The erect thorax/forward head posture (Cluster 4) has not been clearly described in the literature before, most likely as few studies have measured the relationship between the position of the thorax, neck and head in one model. One study of 160 pain free adults found that neck tilt (angle from the horizontal through C7 to the tragus) was not associated with increased upper or lower thoracic curvature (as measured by a mathematically derived curvature of the contour of the spine of the participants) (Raine and Twomey, 1997). However posture was examined in standing in contrast to this thesis that examined sitting neck posture. The interaction of adjacent segments may alter between sitting and standing and this likely accounts for the differences to the findings.

Another difference between the two forward head postures in this study was the larger craniocervical angle in the slumped thorax/forward head posture (Table 2.1, Cluster 3). The larger craniocervical angle indicated that the slumped thorax/forward head (Cluster 3) had a greater amount of upward head tilt compared to the erect thorax/forward head (Cluster 4). It has been hypothesised that a key role of head tilt is to maintain the eyes in a level position (Grimmer-Somers et al., 2008). As result of the thorax being more flexed in the slumped thorax/forward head posture the head will require more upwards tilt to level the eyes, whereas the erect thorax/forward head posture is less flexed and therefore requires less upwards head tilt to level the eyes. Two forward head postures have been described in the aforementioned study by Grimmer (1997). The first forward head posture was described as a head displaced well forward of the vertical reference line (i.e. well forward of full retraction), whilst the second was described as the head just anterior to the vertical reference line (of full retraction) with an upward head tilt. However not a single participant held their head in line with or behind the reference line. Hence all participants in the study were deemed as having a forward head posture. The vertical reference line, therefore dictates the description of forward head posture. In this thesis the two clusters representing forward head posture were referenced to the population mean. The slumped thorax/forward head and erect thorax/forward head had a similar amount of head displacement, had greater mean neck flexion than Cluster 1 and Cluster 2 and were separated by the amount of thoracic flexion (Table 2.1). When the second description of forward head posture (just anterior to the vertical reference line) in the study by Grimmer (1997) was compared to the population mean (in the third data division) it represented the most upright of the quintiles. The difference in how forward head posture has been described by Grimmer (1997) and by this thesis, makes direct comparison challenging.

Intermediate posture (Cluster 2 n = 265 (24%)): Cluster 2 (intermediate) was somewhat in the middle of the two extreme postures (Cluster 1 (upright) and Cluster 3 (slumped thorax/forward head) (Table 2.1). There is little evidence to determine what constitutes neutral sitting posture (Jull, 2008), however the intermediate posture of Cluster 2 in this thesis appears to be in a mid range position at the thorax, neck and head.

4.1.2 Significance of identifying four posture clusters:

Identification of distinctly different posture clusters facilitates greater fidelity when investigating a potential association between neck posture and NP. Both extremes of posture may be associated with NP. Thus, a template for future studies investigating sagittal neck posture has been provided to avoid the potential pitfalls of this type of washout. This section outlines further reasons why the findings are important.

Clusters represent biomechanical profiles and their potential link with neck pain: The angular measures and segmental postural relationships of the identified posture sub-groups (Table 2.1) can be reasonably linked to potential mechanisms reported to be involved in NP via biomechanical theory. Three of the four clusters displayed biomechanical features that have been theoretically linked to postural NP via loading strain on myofascial and articular structures from increased neck tilt, increased head tilt and a more upright thorax and neck (Grimmer-Somers et al., 2008, Silva et al., 2010a, Silva et al., 2010b).

<u>Increased neck flexion:</u> Increased neck flexion has been associated with increased gravitational moment (Szeto et al., 2005a, Edmondston et al., 2011b), increased torque around C7 (Pheasant, 1988) and increased muscular activation of upper trapezius (Szeto et al., 2005b), the superficial cervical extensors (Straker et al., 1997, Burgess-Limerick et al., 1999, Caneiro et al., 2010) and thoracic erector spinae muscles to support the weight of the head (Caneiro et al., 2010). The two clusters representing forward head posture in the current study (Cluster 3 and Cluster 4) both exhibited greater flexion at the neck. Potentially they could be at risk of NP due to either higher levels of compressive loading at the cervicothoracic region or due to muscle fatigue which may in turn lead to muscle pain (Chaffin, 1973).

<u>Increased head tilt:</u> It has been proposed that increased extensor muscle activity is required to counter the flexion moment (downward head tilt) of weight of the head and neck in a forward head position, with extensor moments required around both the atlanto-occipital and cervical joints (Burgess-Limerick et al., 1999). It has been proposed that this may link

head tilt position to NP and headaches (Watson and Trott, 1993). In an upward head tilt position, the deep cervical extensor (sub-occipital) muscles are placed in a biomechanically disadvantaged position (Burgess-Limerick et al., 1999). This shortened position could reduce the tension-generating ability of the sub-occipital muscles, potentially resulting in earlier fatigue and thus pain (Burgess-Limerick et al., 1999). The slumped thorax/forward head posture (Cluster 3) displayed greater upward tilt of the head and may therefore potentially be at risk of NP.

Upright: A more extended neck and thoracic posture could theoretically contribute to pain via continued activation of the erector spinae muscle complex (Caneiro et al., 2010), in turn exposing the cervico-thoracic spine to increased loading via their multi-segmental attachments. Alternatively, continued activation of the erector spinae could potentially lead to fatigue, overload and subsequently pain (Cote and Hoeger Bement, 2010). This mechanism may place those in Cluster 1 (upright) at risk of NP.

Clinical assessment of posture: In clinical practice posture is often assessed using qualitative descriptors against a vertical line of reference which crosses anatomical points in the head, thorax and lower limbs (Silva et al., 2010a) or the head, neck, lumbar spine and lower limbs (Kendall et al., 1993). However, there is no standard method for describing or measuring habitual neck posture (Grimmer-Somers et al., 2008). As mentioned, previous studies have utilised single measures (Oliveira and Silva, 2016, Fernandez-de-las-Penas et al., 2006, Yip et al., 2008) or multiple single measures (Osmotherly and Attia, 2008, Grimmer, 1997, Grimmer, 1996, Silva et al., 2009, Lau et al., 2010, Raine and Twomey, 1997, Hanten et al., 1991, Hanten et al., 2000) to characterise sagittal neck posture. Failure to look at how these singular measures interact may limit their translation into clinical postural assessment. The four clusters in this thesis provide evidence of common patterns of sitting sagittal alignment at the thorax, neck and head that may be easier for clinicians to identify than looking at individual angles of isolated segments. Further research is required to ascertain clinician ability to distinguish between the four clusters.

4.1.3 The association of posture cluster membership with other factors:

In this thesis associations were found between posture cluster membership and other factors from multiple domains (Table 2.3). Female sex was associated with more upright sitting postures (Clusters 1 and 3); after adjusting for sex it was found, being taller was associated with upright posture (Cluster1), being heavier was associated with forward head postures (Cluster 3 and Cluster 4), greater frequency of exercise was associated with upright posture (Cluster 1) and mild, moderate or severe depression was associated with slumped thorax/forward head posture (Cluster 3). However there was no association between neck posture clusters and sitting time or computer use. Some of these associations between posture and other factors are comparable to findings in the previous literature.

Sex: The finding that females sat in more upright posture clusters is similar to previous reports of lumbar spine posture (O'Sullivan et al., 2006, O'Sullivan et al., 2011b, Straker et al., 2009, Straker et al., 2008). However there were no empirical measures of neck posture in these studies, making the findings of this thesis unique. It is not clear why females sit more upright, but it could relate to sex differences in anthropometric factors and/or social factors related to body image (O'Sullivan et al., 2011b).

Anthropometrics: Results from this thesis concur with a prior finding that overweight high school students sit in more neck and thoracic flexion (Brink et al., 2009). Higher BMI has previously been associated with more slump sitting posture in adolescent and adult groups (O'Sullivan et al., 2011b, Mitchell et al., 2008). However neither of these studies considered the neck and head position. Comorbid muscle deconditioning potentially makes it more difficult to hold more erect postures (Smith et al., 2010) (See next section 4.2 Aim 2). To our knowledge there is not any previous evidence that taller individuals are at greater odds of sitting upright.

***Psychological factors**:* Participants with slumped thorax/forward head posture (Cluster 3) had higher odds of depressive symptoms (Table 2.3), consistent with a previous study in adolescents with chronic non-specific musculoskeletal pain for whom slumped postures were associated with higher levels of anxiety and depression (O'Sullivan et al., 2011a). However this is in contrast to the finding that slumped lumbar sitting posture was not significantly associated with higher scores of depression measured by the BDI-Y in the Raine cohort at the age of 14 years (O'Sullivan et al., 2011b). This difference is likely due to this thesis including the position of the head and neck in the posture model, as compared to only trunk position in the former study. A sharp rise in the prevalence of depression in adolescents following the onset of puberty (Thapar et al., 2012) could indicate depression would be a greater influence at 17 than 14. An association between posture cluster membership and depression supports the concept of a mind-body relationship although the direction of this relationship is unknown (Wilson and Peper, 2004, Riskind, 1984, O'Sullivan et al., 2011b).

Lifestyle factors: Participants with upright posture (Cluster 1) were more physically active. This finding appears to be unique. Physical activity can relate to greater back muscle endurance, which has an association with upright posture (Campbell et al., 2011). The current findings are consistent with an intervention study showing exercise can facilitate adoption of more upright postures (Lynch et al., 2010).

Neither sitting time, nor computer use differed between clusters. Previous studies have found transient changes in neck and head tilt posture with different types of information technology used (Briggs et al., 2004). Higher computer use was associated with increased head flexion and neck flexion in males but not females in the Raine cohort at 14 (Straker et al., 2007). Although the former study only used singular postural measures, results from this study do appear contrary, as there was no increased computer use in the two FHP clusters. Sitting time and neck posture has not been previously studied in detail making it difficult to compare the results of this thesis to others. However, greater television use has previously been associated with greater degree of slumped sitting in the Raine cohort at 14 (O'Sullivan et al., 2011b), although television use may not be a true representation of the time spent sitting throughout the day. Potentially the difference in the age at testing may also relate to the difference in results.

4.2 Aim 2: Cross-sectional associations between neck posture cluster membership and neck pain and headaches

The second aim was to investigate if there was association between postural cluster membership and persistent NP, NP made worse by sitting, or headaches, taking into account other potential confounding biopsychosocial factors. After adjustment for sex, height, weight, exercise frequency and depression, no significant difference was found between postural cluster membership and PNP, NP made worse by sitting or headaches (Table 2.4).

4.2.1 Comparison to the previous literature:

Posture and neck pain: The results of this thesis did not support the hypothesis that neck posture cluster membership was associated with NP (Table 2.2). This is in keeping with previous findings of systematic reviews, which reported that there is insufficient evidence to determine an association between spinal sagittal posture and NP (Christensen and Hartvigsen, 2008, Silva et al., 2010b). Some studies included in the systematic reviews (Christensen and Hartvigsen, 2008, Silva et al., 2010b) reported an association between neck posture and NP and some studies did not. Studies published more recently have demonstrated divergent conclusions about the association between neck posture and NP (Oliveira and Silva, 2016, Ruivo et al., 2014) as illustrated below.

A recent study of Portuguese adolescents aged 15 to 18 years included 35 participants with NP that was present at least once a week during the last 3 months, and 35 asymptomatic controls (Oliveira and Silva, 2016). Adolescents with NP displayed less neck tilt (the angle from the horizontal through C7 to the tragus) compared to asymptomatic controls (NP mean (SD): 47° (5°); no NP mean (SD): 44° (4°)). Conversely another Portuguese study of adolescents aged 15 to 17 years found that 105 participants with "regular" NP had greater mean neck tilt (the angle from the horizontal though C7 to the tragus) than 170 asymptomatic controls (NP mean (SD): 46° (6°); no NP mean (SD): 48° (5°)) (Ruivo et al., 2014). No significant differences were found between participants with and without NP for a head tilt (angle from the horizontal through the tragus to the canthus) (NP mean (SD): 16° (6°); no NP mean (SD) 18° (6°)) (Ruivo et al., 2014). Potentially the results of these Portuguese studies were confounded by sex. Neither study adjusted for sex, despite significant differences in posture and the report of NP between males and females in the study by Ruivo et al. (2014). The study by Oliveira and Silva (2016) had almost twice the number of female subjects compared to males. One of the strengths of this thesis is that it adjusted for sex along with other confounding psychological and lifestyle factors that were not taken into account by the two Portuguese studies.

It is difficult to directly compare the results of this thesis to others as no previous studies have clustered posture in the same manner. In the aforementioned study, Grimmer (1996) divided participants into five groups for the purpose of determining extremes of neck posture. This thesis accounted for the limitations of the methods to subgroup neck posture in the study by Grimmer (1996) by the use of cluster analysis. Despite this, the results are similar to findings in the study by (Grimmer, 1996) i.e. sagittal sitting neck posture was not associated with NP.

Posture and neck pain made worse by sitting: This thesis considered NP specific to the task of sitting, to align with the test position used in an attempt to replicate clinical practice of matching aggravating activities to specific objective findings. The results did not support the hypothesis that neck posture cluster membership was associated with NP made worse by sitting (Table 2.4). To our knowledge no previous research has detailed potential relationships between neck posture and NP that is worse in sitting.

Posture and Headaches: The results of this thesis did not support the hypothesis that neck posture cluster membership was associated with headaches (Table 2.4). However this thesis used a broad definition of headache from a single question item; "Do you have now, or have you had in the past, any of the following health professional diagnosed medical conditions or health problems - migraine or severe headache (yes or no)". Previous studies that have investigated the association between NP and headaches have focused on specific headache types (e.g cervicogenic headaches (Jull et al., 2002, Zito et al., 2006), tension type headaches (Fernandez-de-las-Penas et al., 2006, Fernandez-de-las-Penas et al., 2007) and migraine (Zito et al., 2006). A cervicogenic headache is a secondary headache, where the upper cervical spine refers pain into the head via the trigeminal cervical nucleus (Bogduk and Govind, 2009a). Whereas migraine and tension type headaches are primary headaches, which are linked to NP via the trigeminal cervical nucleus (Blaschek et al., 2014, Bendtsen, 2000). It may be that use of the term "severe headache" in this study included headaches that are not physiologically linked to the cervical spine and consequently may account for the lack of association between neck posture and headaches in this study. However, a previous study of 77 females aged 18 – 34 examined the relationship between sagittal standing neck posture and subgroups of headaches (Zito et al., 2006). Despite differences in headache definition and participant demographics the findings were similar to this thesis. There was no difference in the amount of neck tilt (angle from the horizontal through C7 to the tragus) in participants with chronic cervicogenic headache, migraine and a control group that did not experience headaches (Cervicogenic headache mean (SD): 51° (6°), migraine mean (SD): 53° (6°), no headache mean (SD): 50° (5°)). The same study also found there was no difference between head tilt (angle from the horizontal through the tragus to the corner of the eye) across the three groups (Cervicogenic headache mean (SD): 15° (5°), migraine mean (SD): 16° (5°), no headache mean (SD): 13° (6°)).

The finding that headaches were not associated with neck posture is also consistent with a large multicentred randomised controlled trial of 200 participants aged 18 – 60 with cervicogenic headaches (Jull et al., 2002). Patients were randomised into one of four groups. One group received manipulative therapy, the second group exercises only, the third group manipulative therapy and exercises and the fourth group were controls. Postural exercises were included into the exercise programmes of groups receiving exercises. There was a significant improvement in headache frequency and intensity in the treatment groups as compared to controls after treatment. However there was no associated change in neck posture as defined by neck tilt. This suggests that the benefit of exercise on cervicogenic headache symptoms identified in the randomised controlled trial was not mediated by a change in neck posture. Similarly a smaller intervention study of 25 participants aged 20 – 70 years with tension type headache underwent a physiotherapy programme which included manipulation/ mobilisation of the cervical and thoracic spine, manual treatment of the cervical musculature and postural correction exercises (Fernandez-de-las-Penas et al., 2007). After the intervention, headache intensity, frequency and duration showed a significant improvement but there was no alteration in neck posture as defined by neck tilt (angle from the horizontal though C7 to the tragus). Additionally neck tilt was not associated with headache intensity, duration or frequency at any time point in the study (pre intervention, post intervention, or one month after intervention). Similar to the result in the study by Jull et al. (2002), the results suggest that the benefit of intervention including postural exercises on tension type headaches is not mediated by a change of neck posture as defined by neck tilt.

In contrast, other studies have reported an association between sagittal sitting neck posture and cervicogenic headache or tension type headaches. A study of 60 females aged 25 -40 with and without recurrent cervicogenic headaches of at least 5 years duration underwent postural assessment of neck tilt (angle from the horizontal through C7 to the tragus) (Watson and Trott, 1993). The cervicogenic headache group had an estimated 4° less neck tilt (i.e more neck flexion) than a control group without headaches (headache mean (SD): 45° (6°); no headache mean (SD): 49° (3°)). Another study of 50 participants aged 20 – 70 (25 diagnosed with tension type headaches and 25 age and sex matched controls without headaches) also had their posture measured with a single neck tilt measure (angle from the horizontal through C7 to the tragus). Those with tension type headaches demonstrated significantly less neck tilt of 9° (i.e more neck flexion) than the controls (headache mean (SD): 45° (8°), no headache mean (SD): 54° (6°)) (Fernandez-de-las-Penas et al., 2006). Both studies used only a single measure of neck tilt to measure posture, as compared to this thesis that characterised posture with multiple measures. Furthermore the ages of participants ranged widely in the cervicogenic headache study (25 – 40 years) and the tension type headache study (20 – 70 years) in contrast to this thesis that tested an adolescent group.

In summary, comparison of the results of this thesis to the previous literature is complicated by the use of a broad question to characterise headaches in this thesis, and the simpler characterisation of neck posture used in other studies. The finding that neck posture is not associated with headaches is supported by some studies (Fernandez-de-las-Penas et al., 2007, Jull et al., 2002, Zito et al., 2006), but is in contrast to others (Fernandez-de-las-Penas et al., 2006, Watson and Trott, 1993). Further research is needed to clarify the relationship between neck posture clusters and different types of headache.

4.2.2 Significance of the finding that neck posture was not associated with persistent neck pain, neck pain that is worse in sitting and headaches:

This study adds to the body of evidence that has not found an association between posture and NP (Edmondston et al., 2007, Griegel-Morris et al., 1992, Hanten et al., 2000, Straker et al., 2008, Szeto et al., 2002) or between posture and headaches (Fernandez-de-las-Penas et al., 2007, Zito et al., 2006). The findings are contrary to common societal and health care practitioners beliefs (Cho, 2008, Griegel-Morris et al., 1992) and questions the efficacy of population based advice to "sit up straight" or in more neutral postures (see Section 4.6.1 Implications for the management of NP at the population level).

4.3 Aim 3: Neck posture cluster membership in adolescents as a risk factor for the presence of neck pain in young adults

Previous PNP (OR 3.78, 95% CI 2.57 – 5.57) and female sex (OR 1.75, 95% CI 1.16 – 2.65) were found to be risk factors for the presence of PNP at 22 years. The results from this study highlight the importance of taking other related factors (such as sex and previous history of pain) into account. In the univariable analysis, posture cluster membership was associated with the presence of PNP, but this effect was not maintained following adjustment for PNP at 17 and sex. In the final multivariable model, the overall test for significance for differences in odds between clusters for the presence of PNP at 22 was not significant (p=.214, Table 3.2). However, the adjusted estimates of PNP by cluster were highest in Cluster 1 (31.9%) and lowest in Cluster 3 (20.3%), and 28.0% in Cluster 2 and 27.4% in Cluster 4 (Table 3.2). Compared to Cluster 1 (upright), Cluster 3 (slumped thorax/forward head) had decreased odds for the presence of PNP at 22 (OR 0.51, 95% CI 0.27 - 0.97, p=.040, Table 3.2).

4.3.1 Comparison to previous literature:

There has been very limited prospective assessment of the relationship between posture and future experience NP in the literature. This thesis is the first investigation to use comprehensive capture of neck posture via subgrouping.

One prospective study conducted in the Netherlands examined neck posture as a risk factor for future NP. In a cohort of 1334 workers without previous NP in the prior 12 months (mean age 35.7 years) across 34 work places with different tasks, neck flexion (assessed by video recordings) was not a risk factor for developing NP over three years, even after consideration of time spent in neck flexion and biopsychosocial factors that could confound the relationship (RR 1.63 95% CI .70 – 3.82) (Ariens et al., 2001a). Despite differences in the methods in the study by Ariens et al. (2001a) (that measured the percentage of working time with the neck in a minimum of 20°or 45° of neck flexion as compared to this thesis that measured multiple postural measures at a single time point), the results are in agreement that posture is not a risk factor for NP.

Two studies conducted in South Africa examined neck posture as a risk factor for pain in ten body areas in the upper quadrant (head, neck, upper back, right shoulder, left shoulder, mid back, right elbow, left elbow, right hand/ wrist, left hand/ wrist). One hundred and four 15-17 year olds attending high school without upper quadrant musculoskeletal pain in the month prior underwent 2D postural assessment via photographic assessment whilst working at a classroom desktop computer (Brink et al., 2009). Extreme range (both lower and upper quartiles) neck tilt angles (angle from the horizontal though C7 to the tragus) (<35° or > 44°; OR 2.8, 95% CI 1.1 – 7.3) or thoracic angles (angle between lines from C7 to midpoint of manubrium and mid point of manubrium to T8) (<63° or > 71°; OR 2.3, 95% CI 0.8 – 6.3) were significant postural risk factors for developing upper quadrant musculoskeletal pain over six months (Brink et al., 2009). However, odds ratios specific for the development of NP were not reported, making direct comparison to this thesis difficult.

In another study of a cohort of 194 15-17 year olds without upper quadrant musculoskeletal pain in the preceding month, 3D neck posture measures were measured whilst participants worked at a classroom desktop computer (Brink et al., 2015). Increased head flexion (angle from vertical through the midpoint between the left and right tragus to the midpoint of the left and right canthus) (above the 90^{th} percentile in the data) was found to be a risk factor for developing upper quadrant musculoskeletal pain over 12 months (NP score above 90th percentile mean (SD): 82° (8°); no pain mean (SD) 78° (8°)). Upper quadrant musculoskeletal pain was measured via a scoring system, which was a combined score of the number of areas of pain in the upper quadrant and the severity of pain. Odds ratios specific for the development of NP were not reported, making direct comparison to this thesis difficult.

4.3.2 Significance of the finding that adolescent neck posture is not a risk factor for the presence of persistent neck pain in young adults:

Despite use of well-defined posture clusters in late adolescence, this thesis did not find posture in adolescence to be a risk factor for the presence of PNP in young adulthood. Against popular belief the results did not find that the two clusters that represented a forward head posture (slumped thorax/forward head and erect thorax/forward head) to be at greater odds of NP. These findings question the efficacy of population based generic postural advice to "sit up straight" or assume more neutral postures to decrease the risk of future NP (Boyle, 2016, Heyne, 2015, Shahar, 2013) (see section 4.6.1 Implications for the management of NP at the population level)

4.4 Strengths of the thesis

The cross sectional and longitudinal studies presented in this thesis have accounted for a number of limitations in the previous literature, by use of a large population based cohort, with detailed characterisation of posture and broad characterisation of other factors that could potentially confound the relationship between neck posture and NP. This section explores these strengths.

Large community based sample: One of the greatest strengths of this thesis is that it used a large community based cohort. Previous studies examining the association between neck posture and NP have often drawn participants from clinical populations (Hanten et al., 2000, Lau et al., 2010) or workplaces that involve prolonged computer use, an occupational task reported to be associated with NP perhaps as consequence of adopting prolonged neck flexion (Osmotherly and Attia, 2008). Smaller, specialised samples may misrepresent associations in the general population. One prospective study examined a large cohort of workers across 34 work sites, however analysis was performed on mean values from subsamples of the workers at each workplace, rather than at an individual level.

Similarly aged participants: The participants in these studies were of similar age (17 years and 5 years later at 22 years). This means the results of this thesis are unlikely to have been confounded by age. Previous studies have failed to take age into account when examining the relationship between neck posture and NP (Griegel-Morris et al., 1992, Osmotherly and Attia, 2008). Neck pain is reported sometimes in childhood (Brattberg, 2004) and its prevalence steadily rises throughout adolescence (Hakala et al., 2002, Niemi et al., 1996, Vikat et al., 2000, Jeffries et al., 2007). This study has looked at an important transition period, where the participants are leaving school and moving into the work force.

Detailed characterisation of posture: Both inter-segmental relationships and segmental gravity relationships of the head, neck and thorax were examined at the age of 17 years. One of the limitations of the previous literature is that singular postural measures did not take into account the relationship of the spinal segments above or below and how they were positioned in relation to gravity, thus the broader picture of posture characterisation and the associated biomechanical implications may have been missed.

Furthermore this thesis used Cluster analysis methods and thus accounted for a potential washout effect (where the positive association between posture and NP in one postural subgroup may have cancelled out the negative association of another subgroup). Four well-defined clusters of sitting neck posture were supported by previous research findings. Whilst previous studies have attempted to subgroup neck posture (Brink et al., 2015, Grimmer, 1996), the procedures were limited by the division of the data into groups (Grimmer, 1996) or by comparing the data of singular posture measures in the upper and lower quartiles to the two quartiles in the middle (Brink et al., 2015). This thesis is the first of its kind to examine cross sectional and longitudinal relationships between different clusters of sitting neck posture and NP.

Broad characterisation of other factors: Previous research has demonstrated other factors including female sex (Cote et al., 2004, Cote et al., 2009, Fejer et al., 2006b, Hakala et al., 2002, Walker-Bone et al., 2004), small height (Poussa et al., 2005), greater BMI (Luime et al., 2004), greater computer use (Smith et al., 2008b), playing sports that dynamically load the upper limbs (Siivola et al., 2004), depression (Diepenmaat et al., 2006, Rees et al., 2011, Pollock et al., 2011) and work place physical exposures (Ariens 2002) to be associated with NP whilst other studies have determined small height (Poussa et al., 2005), low levels of physical exercise (Siivola et al., 2004) and psychological health (Croft et al., 2001, Ehrmann Feldman et al., 2002) to be risk factors for future NP. To account for any potential confounding effects this study took these factors into account. This was found to be of importance. For example, before adjusting for sex in both the cross sectional and longitudinal studies, posture clusters were associated with and found to be a risk factor for the presence of PNP, however this association appeared to be confounded by the greater representation of females in Clusters 1 and 3. Following adjustment for sex no association between posture and PNP, NP in sitting was found***.***

Use of reliable neck pain questions*:* This study captured NP measures using reliable questions (Kuorinka et al., 1987). Two different constructs of NP were measured. Firstly

PNP symptoms identified participants with pain that was prolonged and recurrent in nature. Previous studies have failed to differentiate between acute and persistent NP symptoms (Griegel-Morris et al., 1992, Hanten et al., 2000, Lau et al., 2010, Osmotherly and Attia, 2008, Ruivo et al., 2014, Szeto et al., 2002, Yip et al., 2008). Secondly, study 1 measured NP made worse by sitting in order to imitate the clinical practice of matching pain-exacerbating positions in the physical examination. However no previous studies have looked specifically at NP made worse in sitting.

4.5 Limitations of the thesis

Limitations in the thesis methods are explored in this section.

Participant age: The results of this thesis are specific to late adolescence and the transition into early adulthood. They may not be applicable to older cohorts.

Participant ethnicity: The participants in this thesis were primarily Caucasian Australians. Potentially cross sectional and longitudinal associations between posture, anthropometric measures, psychological factors, lifestyle factors and NP may alter in populations from other countries, cultures or ethnicity. Therefore the results from this study may not be applicable in other populations.

Postural measurement: The postural measures used in this thesis were calculated from photographs using one distance and five angular measures. Whilst the numbers of measures used in this thesis were greater than in other postural studies and included measures from the head, neck and thorax, they are still crude. The use of photographs to measure alignment cannot assess precise anatomical position of intervertebral translation and rotation that can be detected in x-rays (Gadotti and Magee, 2008). These finer alterations of posture may be important in the development of NP.

Measurement of posture in this thesis was performed in a laboratory setting and participants were asked to sit and look ahead. It may be that the instructions provided and participant awareness that posture was being measured may have influenced the postural behaviour of the participants. Furthermore a photograph represents only a single point in time and is unable to capture postural behaviours such as task related postures and potential variation of posture over time. These unmeasured postural characteristics may affect the relationship between posture and NP. Additionally the findings of this thesis may not be applicable to the relationship between standing neck posture and NP. In this thesis posture was measured at 17 years, without repeated measurement at 22. Stability of cluster membership from 17 to 22 is therefore unknown.

The position of the lumbar spine was not included in the cluster modelling. In the Raine cohort at the age of 14, greater lumbar lordosis was found to be associated with prolonged NP after adjusting for sex (Straker et al., 2009). It is recognised that lumbar posture may be of importance, and could be considered in future modelling.

Muscle performance: It has also been proposed that muscle activity may play a role in NP (Lee et al., 2005, Szeto et al., 2005b) and potentially neck posture (Clark et al., 1979). It is conceivable that there were some differences in neck muscle performance between cluster groups, particularly given there was a greater distribution of females in Clusters 1 and 4. The potential confounding factor of gender to muscle performance cannot be eliminated. This thesis did not measure muscle activation.

Neck pain measures: While there was good characterisation of pain in this thesis (Section 2.2.4 above), the severity, bothersomeness or impact of NP on functional activities was not ascertained. It maybe that more severe NP, more bothersome NP, or NP that affects functional activity may be related to cluster membership.

4.6 Implications for clinical practice

4.6.1 Implications for the management of NP at the population level:

There is a common belief in health care practitioners and society that sitting up straight is "good" posture and slouching is detrimental to spinal health (Boyle, 2016, Shahar, 2013, Felker, 2016, Heyne, 2015). The results of this thesis did not support this notion at the population level, even when accounting for multiple limitations in previous research. Upright neck posture in sitting was not a risk factor for the presence of PNP. Additionally, slumped thorax/forward head posture was not either. This challenges the premise of general postural advice to sit up straight to minimise or prevent neck pain.

A systematic review of the literature that reported that those who received workplace interventions (including advice about relaxed working posture and correct positions) did not have more pain relief than those who received no intervention (Aas et al., 2011). Similarly a postural intervention study of 365 Belgium school children aged 9-11 year olds found that six back education classes improved back posture knowledge but the prevalence of NP did not differ between the control and intervention groups (Geldhof et al., 2006). The findings from the current thesis appear consistent with the findings of these intervention studies. It may be that generic advice on how to sit was not specific enough for individuals (see Section 4.6.2 Implications for the management of NP at the individual level).

4.6.2 Implications for the management of NP at the individuals level:

Assessment of posture is usually performed in the clinical setting to help inform diagnosis and plan treatment (Silva et al., 2010b). The current findings are in line with previous studies that found posture was associated with different factors including female sex (O'Sullivan et al., 2006, O'Sullivan et al., 2011b, Straker et al., 2009, Straker et al., 2008), increased BMI (Brink et al., 2009, Brink et al., 2015) and psychological factors (O'Sullivan et al., 2011b). The same factors have also been found to be associated with NP (Croft et al., 2001, Ehrmann Feldman et al., 2002, Walker-Bone et al., 2004, Luime et al., 2004, Cote et al., 2009, Fejer et al., 2006b, Hakala et al., 2002). The importance of these factors and their interaction with one another may differ between individuals and highlights the need for clinicians to perform comprehensive assessment across domains to assist with the development of individualised, multifaceted intervention strategies.

Postural assessment for individuals with NP may still be useful on an individual basis. In cases where clinicians can exacerbate or decrease NP in individuals by changing postural alignment, specific tailored postural advice may be indicated. However it is unlikely that a change of posture alone will address the cause of the pain. Planning treatment to address the task that is associated with an individual's NP including an evaluation of other dimensions associated with that task may be of greater benefit. The results from this study suggest questions that screen for previous history of NP, current psychological state, and current exercise levels would be of benefit.

4.7 Conclusions

This thesis identified 4 clusters of sitting neck posture, with different biopsychosocial profiles. This study did not find neck posture clusters to be associated with, or a risk factor for the presence of NP. The findings challenge the premise of generic postural advice to sit up straight.

4.8 Future research

A number of research gaps remain in this area. Future research directions to expand on the findings presented in this thesis include:

- This thesis looked at habitual posture measured at a single time point. It is acknowledged that different postural tasks may interact differently with NP. Thus investigation of relationships between usual sitting posture cluster, task postures and pain may be beneficial.

- Measurement of postural variability over time might provide insight into the association between neck posture and NP.
- The association between posture and NP was measured at the age of 17 and 22 in this thesis. It may be that a relationship between posture and NP takes longer to emerge. Continued monitoring of the Raine cohort would be useful to see if a relationship between neck posture and NP develops later in life. This may be of importance, as peak incidence of NP is reported to be between the ages of 30 -45 (Croft et al., 2001). This would also entail ascertaining the stability of neck posture cluster membership over time.
- Future studies comparing sitting neck posture clusters and their relationship to headaches should define headache type. Clearly separating cervicogenic, tension type and migraine headaches (which are related to the upper cervical spine via the trigeminal cervical nucleus) (Bogduk and Govind, 2009a, Bendtsen, 2000, Blaschek et al., 2014) from other headaches (not physiologically linked to the neck) potentially will avoid a washout effect where the positive association between one headache type and neck posture cancels out the negative association of another.

4.9 References

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Appendix

APTA American Physical Therapy Association

1111 North Fairfax Street
Alexandria, VA 22314-1488
703 684 2782
703 684 7343 fax
www.apta.org

November 10, 2016

Karen Richards, MManipTher
Curtin University
Perth, Western Australia, Australia
Email: k.richards@curtin.edu.au

APTA Request Reference: PTJ 112/16; *Phys Ther*. 2016;96(10):1576-1587; Article

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