School of Physiotherapy and Exercise Science

The Effects of Changing Sleep Posture on Spinal Symptoms and Quality of Sleep in Cervical and Lumbar Symptomatic Participants

Doug Cary

This thesis is presented for the degree of

Doctor of Philosophy

of

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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: 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), approvals were;

- Masters PT 0169
- PhD HR 140/2014

Doug Cary

01/12/2019

Abstract

While there has been enormous growth in sleep, spinal symptoms research and quality of sleep, little attention has been paid to the possible effects sleep posture may have on waking spinal symptoms and quality of sleep. Patients presenting to health services with waking spinal symptoms like pain and stiffness not present on going to bed, are asked about their sleep posture and sleep system (i.e., bed, pillow and mattress). Self-report of sleep posture has been found to be unreliable and calls into doubt a large proportion of the current body of literature. As part of their treatment, patients are advised to avoid certain sleeping postures thought to be provocative. This approach appears to have sound clinical reasoning and biological plausibility, and anecdotal evidence suggests that changing sleep posture may reduce waking spinal symptoms. However, there is limited research examining relationships between sleep posture and waking symptoms on which to base advice, and it is not known if patients can change their sleep posture if requested to do so.

Sleep postures are generally classified as supine, side lying or prone. Classification is simplistic, with supine defined as lying on the back, prone lying on the stomach and all other positions are considered side lying. When considering the potential that a sleep posture could provoke spinal symptoms, it is important to know whether the posture involves end range rotation and/or extension. It is believed anecdotally and theoretically, that these postures are more likely to increase compression and torsion load on spinal tissues. There is broad consensus that supine is supportive and prone provocative of spinal symptoms, however this has not been confirmed. Adults spend the largest period of time in side lying, however, side lying contains an array of postures, some of which are claimed to optimise spinal recovery, while others involve end range postures and are possibly provocative to spinal tissues. For this reason, it may be important to consider sub-classify side lying based upon possible tissue load, rather than using one homogeneous side lying classification.

A large percentage of sleep research is conducted in high technology sleep laboratories that are expensive to operate, induce altered patterns of sleep, are of limited availability and are largely reserved to examine pathological groups. These barriers limit research and generalisability of findings. A recent systematic review identified the need for non-invasive, low cost and user-friendly objective measurements of sleep, that can be deployed into non-laboratory environments.

The aim of this doctoral thesis was to examine relationships between sleep posture, waking spinal symptoms and quality of sleep. Due to the lack of on an objective measure of sleep posture, we first needed to select equipment and develop a recording protocol to accurately measure sleep posture in the home environment. To achieve this, 20 health professionals (physiotherapists and chiropractors) viewed a pre-recorded video, showing randomised sleep postures under natural and infrared light situations, with a variety of bed coverings to represent the home sleep environment. Participants classified the viewed sleep postures into six categories, including two new side lying postures. Viewing was repeated after two days. It was

found that reliable and valid assessment of each sleep posture could be achieved under a variety of light conditions and bed coverings.

Using this recording protocol, we demonstrated in a pilot study (N = 15), that capturing good quality sleep posture data were possible and there was no first night effect in the home environment. Participants who spent less time in rotated and extended postures, had less symptoms per month, but these findings were non-significant.

The final phase of this thesis, divided into two parts, was to examine relationships between sleep posture, waking symptoms and quality of sleep in a control and symptomatic groups. Firstly, in a cross-sectional study to determine if participants slept differently. Data were collected from 53 participants in three groups (i.e., Control n = 20, Lumbar n = 20 and Cervical n = 13) and compared. Participants in the symptomatic groups spent more time in provocative postures than the Control group, significant in the Cervical group and nearly significant in the Lumbar group (p = .52). Participants in the symptomatic groups also reported poorer outcomes in all measures of pain, disability, quality of sleep and quality of life compared to participants in the Control group. Secondly, a prospective uncontrolled intervention trial was conducted in which symptomatic participants were advised to change their sleep posture. Participants in the symptomatic groups were then re-assessed at 4 and 16 weeks after baseline. Following the postural education intervention, participants in both groups were able to reduce the time they spent sleeping in provocative sleep postures and reported significant improvements across a broad range of pain, disability, quality of sleep and quality of life measures at 4 and 16 weeks after baseline. This was more so in the Lumbar group. This thesis has made a significant and original contribution to the area examining sleep posture, waking spinal symptoms and sleep quality.

Acknowledgements

Never say never!

In 1992, at the completion of my post graduate year in musculoskeletal physiotherapy, I was convinced that I would never undertake any further research. Research was done and dusted and it was now clinical practice for me. Yet in 2019, after nine years of research and writing, I find myself dotting ‘i’s and crossing ‘t’s in my PhD. thesis.

What had changed to propel me in a direction that I had long ago, decided to never pursue? Pure and simple, my clients. Without them, I would have never commenced this journey and without them, I would never have had the data from which to draw any meaningful conclusions. My sincere and grateful thanks to those in the Esperance community, who bravely welcomed me into their bedrooms, armed with cameras and recording equipment.

A journey this long requires a team effort. I would firstly like to thank my wife Melissa, for her enduring support and endless considerations. She aspires to bring the best out in all people and in supporting me, she has enabled this PhD. To take wings and fly. For that reason, Melissa is as much a part of this PhD as me and I will always be grateful. I started this journey with some basic skills. I was entrepreneurial, persistent and happy to apply myself to new endeavours; skills that I attribute to as coming from my father. My mother opened my eyes to reading, language and creative writing at an early age and these skills have been of invaluable assistance throughout my PhD. journey. Thank you also Mum, for proofreading early and late drafts of this manuscript.

From conception to completion of this PhD., I have been fortunate to receive from Kathy Briffa, the ongoing guidance on the what’s and the why’s of a PhD. Her elegance of written phrase, knowledge of statistics and understanding of the machinery that is a PhD., surely puts her up there as one of the best ‘PhD. mechanics’ around. I would also like to thank Michele Sterling for her support as my co-supervisor and to thank both Roger Collinson and Andrea Jacques for their invaluable contribution with statistics. Late in my PhD. journey, the need to undertake a scoping review to review current literature was identified and Leanda McKenna kindly accepted to join our team. Her energetic demeanour, quick response to queries and precise mind, made short work of what could have been a challenging process and I am very grateful for her willing contributions. Thank you also to Rebecca Clayton for her assistance in reviewing scoping review papers.

I would also like to acknowledge the contribution of an Australian Government Research Training Program Scholarship in supporting this research.

Doug Cary November 1, 2019.

Attributions

Chapter 3

Appendix 2 Examining the relationship between sleep posture and morning spinal symptoms in the habitual environment using infrared cameras

Authors and Contributions

D Cary. Conception and design, Acquisition of data, Analysis and statistical method, Interpretation and discussion, Review and final approval

R Collinson. Statistical method, data analysis and interpretation

M Sterling. Review and final approval

K Briffa. Conception and design, Interpretation of the data and discussion, Review and final approval

Appendix 4 Examining the validity and reliability of a portable sleep posture assessment protocol, using infrared cameras, under a variety of light and bed cover situations in the home environment

Authors and Contributions

D Cary. Conception and design, Acquisition of data, Interpretation and discussion, Review and final approval

R Collinson. Statistical method, data analysis and interpretation

M Sterling. Review and final approval

K Briffa. Conception and design, Analysis and statistical method, Interpretation and discussion, Review and final approval

Chapter 6

Appendix 22 Identifying relationships between sleep posture and nonspecific spinal symptoms in adults: A scoping review

Authors and Contributions

D Cary. Conception and design, Acquisition and analysis of data, Interpretation and discussion, Review and final approval

K Briffa. Conception and design, Review and final approval

L McKenna. Conception and design, Acquisition and analysis of data, Interpretation and discussion, Review and final approval.

Publications and Abstracts

List of Publications

Appendix 2

Cary D, Collinson R, Sterling M, Briffa NK. 2016. Examining the relationship between sleep posture and morning spinal symptoms in the home environment using infrared cameras. J Sleep Disorders: Treatment and Care 5(2). doi: 10.4172/2325-9639.1000173

Appendix 4

Cary D, Collinson R, Sterling M, Briffa NK. 2019. Examining the reliability and validity of a portable sleep posture assessment protocol, using infrared cameras, under a variety of light and bed cover situations in the home environment. WORK 63(2). doi 10.3233/WOR-192930

Appendix 22

Cary D, Briffa K, McKenna L. 2019. Identifying relationships between sleep posture and non-specific spinal symptoms in adults: A scoping review. BMJ Open 9(6), e027633. doi: 10.1136/bmjopen-2018-027633

List of Abstracts

Appendix 23

Cary DH, Collinson R, Sterling M, Briffa K. 2013. Measurement of sleep posture in the home environment. Australian Physiotherapy Association 'New Moves' Conference, Melbourne Australia October (Abstract Supplement).

Appendix 24

Cary D, Collinson R, Sterling M, Briffa K. 2014. Do we know our sleep posture and does sleep posture influence spinal symptoms? Sleep and Biological Rhythms 12 (Supplement 1, pg 23) doi:10.1111/sbr.12082

List of Abbreviations

REM	Rapid eye movement
Non-REM	Non-rapid eye movement
ZPJ	Zygapophyseal joint
IVD	Intervertebral disc
FSU	Functional spinal unit
MRI	Magnetic resonance imaging
N	Newtons
mm	Millimetres
VAS	Visual analogue scale
BMI	Body mass index
LBP	Low back pain
cLBP	Chronic low back pain
NRS	Numerical rating scale
OSA	Obstructive sleep apnoea
LPPI	Long periods of postural immobility
PSL	Provocative side lying
SSL	Supported side lying
PSG	Polysomnography
IR	Infrared
ICC	Intraclass correlation coefficient
95% CI	95% confidence interval
MCID	Minimal clinical important difference
PRO	Patient reported outcomes
RMQ	Roland-Morris Disability Questionnaire

NDI	Neck Disability Index
SFI	Spin Functional Index
ISI	Insomnia Sleep Index
PSQI	Pittsburgh Sleep Quality Index
SF36 PS	Short Form 36 Physical Score
SF36 MS	Short Form 36 Mental Score
ANOVA	Analysis of variance
PICO	Population, intervention, comparison and outcome

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Chapter 1. Introduction

Sleep is considered essential for human mental and physical recovery (Cabot & Beckham, 2005; Helmanis, 2006; Xie et al., 2013). Yet every night, a proportion of the population goes to bed without symptoms, only to experience waking spinal symptoms and/or poor quality sleep, while others with already existing spinal symptoms, will wake with exacerbations of their retiring symptoms (Desouzart, Vilar, Melo, & Matos, 2014; Goldman, 2005; Gordon, Grimmer, & Trott, 2007a; Kraemer, 2011).

Spinal symptoms are common and mostly occur in the cervical and lumbar regions, with a one-year point prevalence ranging from 30 to 50% for cervical pain (Hogg-Johnson et al., 2008) and 38% for of lumbar pain (Hoy et al., 2012). The prevalence of both cervical and lumbar pain has increased markedly (cervical 21.1% and lumbar 17.3%) over the past 25 years, and these rates are expected to continue rising (Hurwitz, Randhawa, Yu, Côté, & Haldeman, 2018). Other types of symptoms like stiffness and bothersomeness, still important to patients, are less well documented.

It has been postulated that poor sleep posture during the night may be responsible for the production of both waking cervical (Gordon, Grimmer-Somers, & Trott, 2010; Gordon, Trott, & Grimmer, 2002; Lee et al., 2016) and lumbar symptoms (Gracovetsky, 1987). It was determined in young military recruits, that 33% had the most intense spinal pain during sleep hours or on waking and that for 50% of the recruits, the spinal pain was significant enough to cause disruption to their sleep routine (Desouzart, Vilar, et al., 2014). Historically, research into sleep posture has either used non-validated tools or technology that is not widely available. Further, current sleep posture classifications generally divide sleep posture into supine, prone and side lying. With adults spending up to 70% of their sleep time in side lying (De Koninck, Lorrain, & Gagnon, 1992; Gordon et al., 2007a) and taking biomechanical stress into account, it is logical to consider whether the side lying classification should be divided into sub-posture classifications. Intermediate postures associated with side lying have been acknowledged (Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011) and intermediate side lying postures could be considered with respect to their likelihood or not, of provoking pain-sensitive spinal structures. Anecdotal and theoretical evidence suggests that mechanical load induced by some sleep postures, like prone, may provoke spinal pain (Desouzart, Matos, Melo, & Filgueiras, 2016; Gordon et al., 2007a) due to increased compression or elongation loads on spinal tissues (De Koninck et al., 1992; Gracovetsky, 1987).

In upright and lying down postures, loads experienced by spinal structures include compression, elongation, torque and shear. Gravity is a source of spinal compression, but the major source is derived from muscle contraction (Dolan, Earley, & Adams, 1994; Kingma et al., 2001). Compression is primarily attenuated by the vertebral bodies, intervertebral discs (IVD) and zygapophyseal joints (ZPJ) (Pollintine, Przybyla, Dolan, & Adams, 2004). When lying down and resting, spinal compression due to gravity and muscle contraction is reduced, creating a low compression environment and reducing the role for load attenuating structures. A reduced gravity environment, potentially allows an increased range of spinal movement, due to reduced anular stiffness (Iatridis et al., 1998) and reduced ZPJ contact (Pollintine, Przybyla, et al., 2004). The potential combination of increased range of movement and altered loading patterns, may result in additional loading of viscoelastic collagenous tissues like anular IVD fibres (Krismer, Haid, & Rabl, 1996) and ligaments, rather than bony structures (Adams & Hutton, 1981). Viscoelastic tissues are vulnerable to sustained or repeated low elongation loads and undergo predictable mechanical and viscoelastic changes. These include creep, hysteresis and fatigue failure. In an in vivo experiment, healthy participants sustained 10 minutes of spinal flexion, which resulted in spinal creep and in 50% of the participants, muscle spasms, with the authors suggesting this occurred secondary to viscoelastic tissues micro-damage (Solomonow, Baratta, Banks, Freudenberger, & Zhou, 2003). Pro-inflammatory chemicals have been mapped in harvested feline spinal ligaments subjected to three, 10 minute applications of low load (Solomonow, 2012), providing a possible mechanism to explain spinal symptoms following a low load viscoelastic injury.

Sleep posture has been associated with quality of sleep. Specifically, some sleep postures result in increased biomechanical load on the spine, causing pain, stiffness and poorer quality sleep (Gordon et al., 2010; Lee et al., 2016). A bi-directional association between spinal pain and sleep quality has been identified (Alsaadi, McAuley, Hush, & Maher, 2012; Finan, Goodin, & Smith, 2013). That is, increased pain during the day, results in poorer quality of sleep that night, and poorer quality of sleep results in increased pain the following day. At any given time around the world, one third of the adult population experiences poor quality sleep (Ohayon, 2002). Poor quality of sleep is subjectively determined by delayed sleep onset, more awakenings after sleep onset, increased total wake time, and poor continuity of sleep (Akerstedt & Gillberg, 1990; De Koninck, Gagnon, & Lallier, 1983). Therefore, factors like sleep postures that provoke pain, potentially causing increased awaking, could impact on sleep quality. Poor sleep quality is significantly associated with adverse health outcomes for adults (Meerlo, Sgoifo, & Suchecki, 2008; Nitter, Pripp, & Forseth, 2012) and is predictive of musculoskeletal pain in pre-adolescents, adolescents, young adults (Auvinen et al., 2010; El-Metwally, Salminen, Auvinen, Kautiainen, & Mikkelsson, 2004; Harrison, Wilson, & Munafò, 2014; Millman, 2005) and adults without pain (Nitter et al., 2012). For this reason, it is important to identify any factor that potentially could adversely affect an individual's ability to maintain an asleep state.

While some sleep research has examined the role sleep posture may have on waking spinal symptoms (Desouzart, Filgueiras, Melo, & Matos, 2014; Desouzart et al., 2016; Gordon et al., 2007a) and sleep quality (Gordon, Grimmer, & Trott, 2007b), none of these studies used validated, objective measures to confirm self-reported sleep postures.

In summary, there is limited research examining the relationships between sleep posture, waking spinal symptoms and sleep quality, on which to base clinical advice to patients experiencing waking spinal symptoms and interrupted sleep.

1.1 Problem Identification

For the clinician treating and advising patients about the possible influencing effects of sleep posture on waking spinal symptoms, there is much opinion (Courtial, 1970; Edwards, 2005; Escolar-Reina et al., 2009; McDonnell, 1945; McKenzie & May, 2006; Travell & Simon, 1992, 1999; Yim, 2015) but limited evidence (Desouzart et al., 2016) to guide management and advice.

An initial review of the sleep literature, with a focus on sleep posture, revealed the majority of research is laboratory-based and primarily focused on sleep pathologies like insomnia, obstructive sleep apnoea, sudden infant death syndrome (Dwyer, Ponsonby, Blizzard, Newman, & Cochrane, 1995; Fleming et al., 1990; Lichstein et al., 2006; van Maanen et al., 2012), ulcer prevention (Hsia et al., 2009) and design of sleep systems (Gordon, Grimmer-Somers, & Trott, 2009; Leilnahari, Fatouraee, Khodalotfi, Sadeghein, & Kashani, 2011; Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011). We conducted a more recent scoping review examining relationships between sleep posture and waking spinal symptoms and identified only four relevant studies (Cary, Briffa, & McKenna, 2019). A recent systematic review examining non-laboratory measurements for sleep pathology, identified the need for non-invasive, low cost and user friendly objective measurements of sleep, that can be deployed in non-laboratory environments (van De Water, Holmes, & Hurley, 2011). Further, ergonomic sleep studies require long periods of monitoring to accommodate for the variations in nightly posture and habituation (Willemen et al., 2012). Currently, there is no cheap, portable, valid and reliable method to assess long-term sleep posture, on which to base patient treatment decisions and advice in regards to waking spinal symptoms.

1.2 Thesis Hypothesis

The first hypothesis we have considered, is that sleep posture and the time spent in sleep postures are different in participants who wake with and without spinal symptoms. The second hypothesis is that with education, sleep postures can be changed, resulting in waking spinal symptom reduction and possibly an improvement in other domains associated with sleep.

1.3 Aim and Objectives

The aim of this research was to investigate the relationship between sleep postures, waking spinal symptoms and quality of sleep in participants with and without waking spinal symptoms.

1.3.1 Objectives

To achieve this aim, six objectives were constructed to be tested.

1) The first objective of this study was to identify appropriate equipment and sampling procedures, henceforth called the recording protocol, to enable

the study of sleep postures with minimal intrusion, in a home environment.

2) The second objective was to conduct validity and inter- and intra-rater reliability testing of sleep posture classifications, including the sub-classification of side lying postures.

3) Participants involved in sleep research conducted in sleep centres exhibit a phenomenon called the first night effect. To counter this, researchers discard data from the first one or two nights. Therefore, the third objective was to identify if a first night effect does or does not occur using the recording protocol in the home environment.

4) The fourth objective was to determine the accuracy of self-report for sleep postures, including sub-classified side lying in the home environment.

5) Due to the vanguard nature of the research, the fifth objective was to examine in a larger group (N = 53), a broad range of differences between symptomatic and control participants.

6) The final objective was to assess whether participants with waking spinal symptoms were able to change their sleep posture following an education intervention and 4 weeks of practice, and if so, what changes occurred in the domains of musculoskeletal symptoms, disability, sleep quality, and quality of life at 4 and 16 weeks after the baseline assessment.

1.3.2 Overall Study Design

The first objective was achieved via discussions with professionals in the security and sleep research fields, to identify and then test the appropriateness of selected equipment. After functionality of the equipment and protocol was confirmed, the second objective was examined by asking health professionals (N = 20) with various levels of clinical experience, to view a random sequence of the six sleep postures, under varying light sources and degrees of bed covering to ascertain validity. Viewing was repeated on two separate occasions to ascertain the reliability of the recording protocol.

The third and fourth objectives were examined with a group of 15 volunteers, each recorded for two nights using the recording protocol while sleeping in their home environment. The accuracy of self-report was further tested in the subsequent larger study (N = 53).

The fifth objective was addressed using data collected from a non-randomised cross-sectional cohort of 53 participants, 33 with waking spinal symptoms (i.e., 13 cervical and 20 lumbar) and 20 in our control group.

The 33 participants who experienced spinal symptoms, were included in a prospective study addressing the final objective. Participants received education in relation to recommended sleep postures and the benefits of changing their sleep posture. Participants were then re-assessed at 4 and 16 weeks after the baseline assessment.

Limitations to this research were noted from the start. Because this research is examining sleep posture and not examining sleep neurophysiology, sleep posture data collection commenced when participants turned out their lights and assumed a stable sleep posture, not when they actually fell asleep, as this could not be determined. Study participants needed to have ease of movement around their bed and for this reason confounding factors such as medical conditions, age and medications were used to exclude persons whose natural movement was limited. Finally, participant numbers were limited. This was mostly due to the rural and remote geographical location (i.e., Esperance, Western Australia) of the main researcher, limiting the potential source of participants. Australian Bureau of Statistics 2016 Census records the total population aged between 19 and 44 years as 3019 (Statistics, 2016). It was also limited as the main author had been practicing in Esperance for more than 10 years, and anyone that had previously been treated for neck or low back pain by the main author were excluded. Further, recruitment was limited by volunteers' concerns or their partner's concern about being videoed while asleep.

Participants were enrolled consecutively, but restriction in participants meant it was not feasible to have a randomised control group for the prospective study. To optimise the study design, participants in the symptomatic groups enrolled in the baseline assessment, also participated in the 4 and 16 week follow-ups.

1.4 Study Significance

In clinical practice it is common to treat patients with waking spinal symptoms. Treatment to date is based on anecdotal knowledge and clinical trial and error. This study will provide tools and fundamental evidence for the role that sleep posture may have in waking spinal symptoms. As such, this study will inform the treatment of patients with waking spinal symptoms and guide the development of larger and more definitive trials that will ultimately guide evidenced based management of waking spinal symptoms with respect to sleep posture.

1.5 Study Overview

This thesis consists of seven chapters.

Following this introductory chapter, relevant background information in regard to the sleep cycle, spinal anatomy and biomechanics, types and possible sources of waking symptoms are presented in Chapter 2. Several aspects of sleep posture are explored including the development, classification, measurement and relationship with spinal symptoms. Factors influencing why people might choose a particular sleep posture and their ability to change their sleep posture are also discussed.

In Chapter 3 the development and testing of a portable and low-cost method to assess sleep posture is described. The validity and reliability of this novel sleep posture assessment method (including sub-classified side lying) was tested under different light conditions and bed coverings to represent the home environment. The recording protocol was then field tested as a pilot study in home environments. Testing included examination for the first night effect and accuracy of self-reported sleep postures.

The methodology for the non-randomised, cross-sectional cohort and prospective longitudinal studies is presented Chapter 4. Control and symptomatic groups (i.e., cervical and lumbar) were assessed at baseline and the symptomatic participants were reassessed at 4 and 16 weeks after an education-based intervention aimed to decrease time spent in provocative sleep postures. In addition to sleep posture, a broad range of pain, disability, quality of sleep and quality of life measures were collected.

Results from the cross-sectional and longitudinal studies are presented in Chapter 5.

In Chapter 6, the findings of a scoping review undertaken to examine relationships between sleep posture and spinal symptoms in adults are presented. As this PhD. spanned nine years from conception to data analysis, it was believed important to examine the findings described in Chapter 5, in light of current research.

Lastly, in Chapter 7 our results are discussed in context with the current understanding of research in sleep posture with regard to waking spinal symptoms and quality of sleep. This chapter also contains our conclusions and a reflective evaluation of our studies and suggests areas for future research.

1.6 Chapter 1 Key Points

- Sleep is essential for optimal physical and mental recovery
- Anecdotally, sleep posture may contribute to waking spinal symptoms and poor quality of sleep but there is a lack of research using validated measures
- There are plausible biomechanical reasons as to why sleep posture could contribute to waking spinal symptoms.

Chapter 2. Background

In the first section of Chapter 2, the components of the sleep cycle are described with particular reference to levels of consciousness and changes of posture. The following sections examine relevant spinal anatomy and biomechanics and the chapter closes by examining possible sources of spinal symptoms and the classification, measurement and influencing factors of sleep posture.

2.1 Sleep

2.1.1 Sleep Stages

Starting in the 1920s, measurement of sleep depth using electroencephalograms enabled researchers to investigate brain activity during sleep. Due to high levels of brain function noted, the myth that the brain was resting while asleep was overturned and sleep was subsequently divided into periodic sleep cycles of rapid eye movement (REM) and non-REM (NREM) (Figure 1).

Human sleep is commonly classified into five stages, four non-REM and one REM. While there is individual variation, the sleep cycle progresses from Stages 1 to 5 and is repeated regularly through the night, each cycle lasting from 90 to 140 minutes. The first four stages are non-REM sleep. Stage 1 (5 - 10 minutes) and Stage 2 involve periods of drowsiness and light sleep. Brain activity involves thoughts like contemplation, planning and evaluation (Fosse, Stickgold, & Hobson, 2001). Changes in sleep posture are also common in Stages 1 and 2 (Hobson, 2005). During Stage 2, brain waves transition from alpha to theta, with periods of spontaneous muscle contraction and relaxation. The heart rate slows and body temperature decreases as the body prepares for deep sleep. Stages 3 and 4 are characterised by theta and delta brain waves, representing deep sleep and a period of time from which it is difficult to wake. During the REM stage, respiration, eye movement and brain activity increases as a period of intense dreaming commences. With the increased mental activity, face and limb muscles twitch, but large voluntary muscle groups are paralysed and while we imagine we move, we do not (Harrington, 2014). As the night progresses, there is a greater portion of each cycle spent in REM sleep; starting initially at around 10 minutes and extending to 60 minutes in the last cycle of sleep.

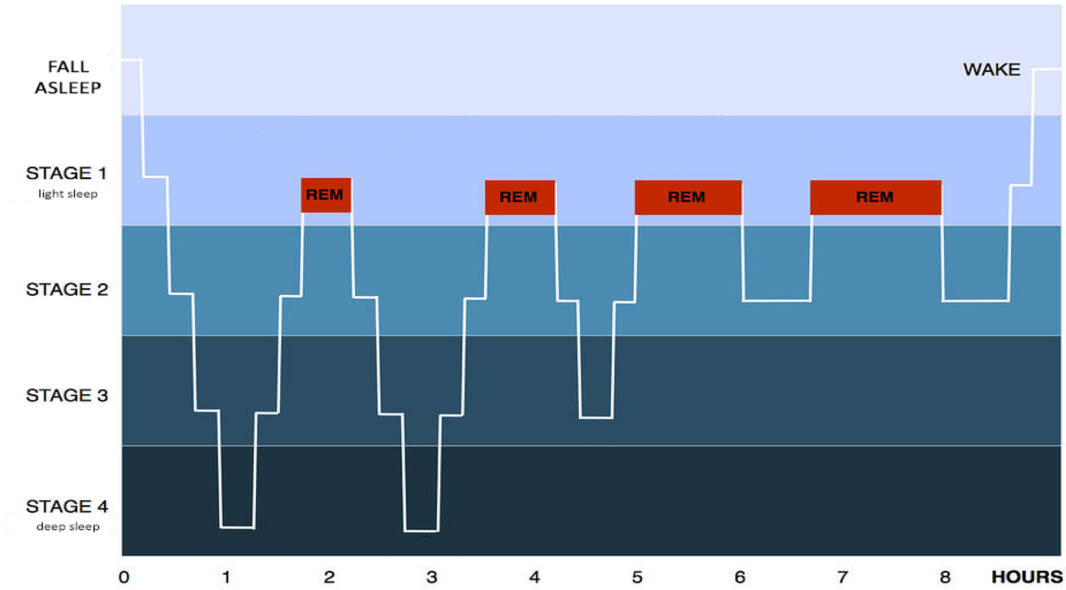

Figure 1. A cycle of ascending and descending rhythms of approximately 90 minutes and consisting of five sleep stages, characterises human sleep patterns. Each cycle finishes in REM sleep, in which intense dreaming occurs, often followed by a brief period of awakening. The time spent in REM increases with each subsequent cycle and is associated with learning and memory organisation. Stage 1 and 2 involve light sleep, while Stages 3 and 4 involve deeper, slow wave sleep associated with tissue healing and recovery. Adapted from (Kurlak, 2014).

2.1.2 Posture Shifts

Posture shifts and muscle activity are periodic and mainly occur in transition between sleep stages and during waking stages (Hobson, 2005). Long periods of postural immobility are associated with non-REM sleep (i.e., deep sleep). With regard to transitions, posture shifts mostly occur in the ascending stages, (e.g., Stage 4 and 3 to Stage 2 or to a REM stage) (De Koninck et al., 1992; Hobson, Spagna, & Malenka, 1978). Transition from Stage 2 into either REM (light sleep) or Stage 3 and 4 (deep recovery sleep), is strongly linked to body movements. It was noted that if movement occurred in Stage 2, there was a low probability (14%), that participants would transition into Stage 3 or 4 (i.e., deep, recovery sleep). Rather, with movement in Stage 2, the majority of people transition into REM (i.e., light) sleep (Muzet, Naitoh, Townsend, & Johnson, 1972). To optimise the amount of deep sleep, identifying and reducing factors that might contribute to posture shifts in Stage 2, could increase the amount of time spent in the restorative stages of sleep. It was noted in participants with ages ranging from 3 to 80 years, that while there were sleep posture preferences within age groups that follow the general ontogenetic trend (i.e., with increasing age, less time in prone and increased time in side lying), the actual sleep postures assumed by participants were independent of sleep stages (De Koninck et al., 1992).

Posture shifts also commonly occur during waking, a brief period of time following each REM stage. The REM stage is commonly associated with experiences of hallucinations and dreaming, whereas waking, quiet waking and sleep onset, are

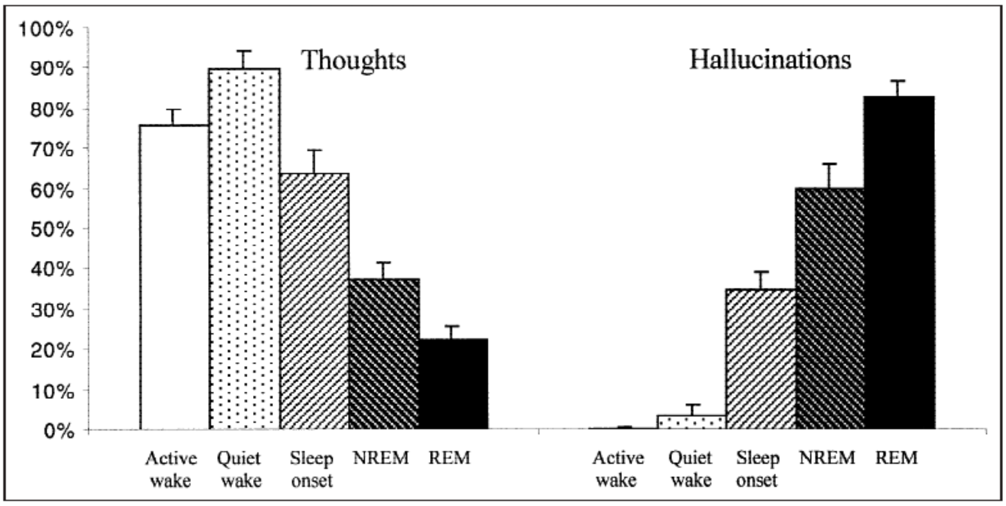

Figure 2. Percentage of reports with thoughts and percentage of reports with hallucinations in each wake-sleep state (Fosse et al., 2001).

associated with thoughts and higher mentation (Figure 2). Thoughts include contemplation, brooding, evaluation, planning and understanding, and occur whether in a home or a sleep centre environment (Fosse et al., 2001). It is plausible, that during a stage of sleep commonly associated with posture shifts (i.e., waking), the thinking part of the brain is actively engaged and may be able to evaluate and decide what sleep posture to move into next.

2.1.3 Summary of Section 2.1 Sleep

Human sleep is characterised by several, repeated cycles a night of deep and light sleep, with periods of brief waking between. Muscle activity and posture shifts are also periodic and associated with transitions between sleep stage and brief awakenings. While changes in sleep postures are associated with transitions between stages of sleep, sleep postures adopted are not sleep stage related. As a consequence of higher levels of thought during periodic awakenings, it is plausible that sleeping posture could be consciously determined before transitioning back into deeper sleep states.

Spine anatomy and terminology are reviewed in Section 2.2, Spine Anatomy.

2.2 Spine Anatomy

2.2.1 Terminology

Anatomical descriptions are based upon four imaginary planes that divide the body into parts (Figure 3):

- Median plane: A vertical plane dividing the body equally into left and right halves.
- Sagittal planes: Vertical planes, parallel to the median plane dividing the body into left and right parts.
- Frontal (coronal) planes: Vertical planes at right angles to the median plane dividing the body into anterior (front) and posterior (back) parts.
- Transverse (horizontal) planes, at right angles to sagittal and frontal planes dividing the body into superior (above) and inferior (below) parts.

2.2.2 Spine Structures

The musculoskeletal system of the spine consists of the skeletal system; vertebrae and interposing zygapophyseal joints (ZPJ), the ribs and pelvis and the soft tissue system; namely muscles, intervertebral discs (IVD), ligaments, joint capsules, vascular and neural structures.

The basic building block of the spinal column is termed the functional spine unit (FSU) and consists of adjacent vertebrae, IVD, ZPJs and ligaments that allow mobility while protecting the vital spinal cord. The spinal column gains additional stability via

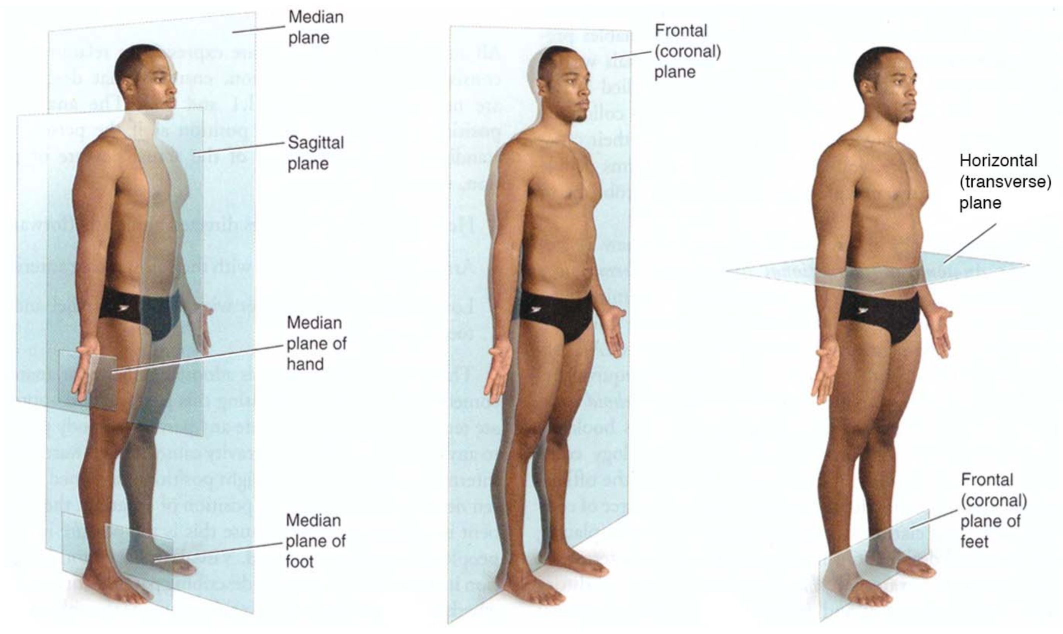

Figure 3. When discussing movement, posture and relative position of structures, anatomical descriptions are based upon the three cardinal planes; sagittal, frontal and transverse. Figure reproduced with permission from Moore, Dalley, and Agur (2006).

the ribs, which assist in protecting the vital organs, and the pelvis, which assists in load transfer from the lower limbs. The vertebral column consists typically of 33 vertebrae; seven cervical, 12 thoracic with associated ribs, five lumbar, five fused sacral and four separate coccygeal bones. There is a general trend from superior to inferior of vertebrae increasing in size, reaching a peak at the first sacral vertebra and reflecting greater load dissipation capacity. Conversely, greater ranges of motion are achievable in the higher portions of the spine, with 50% of cervical range occurring in the first two spinal segments (Bogduk & Mercer, 2000). The five sacral vertebrae are fused, forming part of the pelvis and the four coccygeal vertebrae are fused representing a rudimentary tail (Jull et al., 2015).

The vertebrae of the spinal column are aligned in the shape of an 'S', when viewed in the sagittal plane, creating four curvatures. The cervical and lumbar curvatures are convex anteriorly (lordosis), while the thoracic and sacral/coccyx curvatures are convex posteriorly (kyphosis) (Moore et al., 2006).

Apart from the first two cervical vertebrae, each vertebra is similar in structure and consists of two parts, a vertebral body and a vertebral arch. Between each vertebral body is an IVD, which is generally divided into two portions; the inner nucleus pulposus and outer anulus fibrosus. In the cervical spine, there is also a periosteo-fascial tissue in the postro-lateral region, replacing the anulus fibrosis seen in other parts of the spine, which migrates medially and by the third decade becomes a horizontal cleft (Bogduk & Mercer, 2000). Elsewhere, the anulus fibrosus consists of lamina layers with each layer aligned at 60 degrees to the preceding lamina, providing a mobile and strong structure resisting torsion loads. The nucleus pulposus is gel like in consistency till middle age and assists in load transfer. Within 4 hours of vertical loading, the fluid volume of the IVD will reduce between 6 and 13%. Nucleus pulposus fluid volumes decrease with increasing age and the overall spinal column length is also reduced and becomes stiffer with increasing age

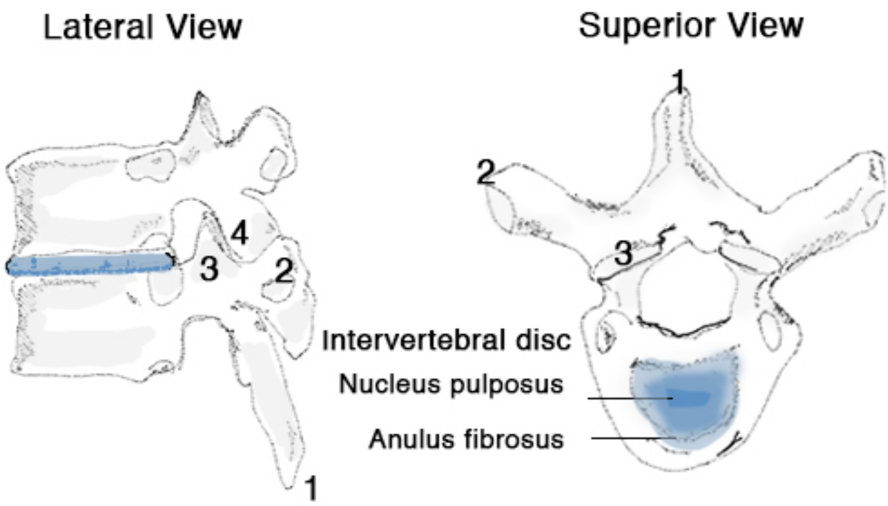

Figure 4. Key vertebral landmarks include: 1 spinous process, 2 transverse process, 3 superior process of the ZPJ, and 4 inferior process of the ZPJ. The IVD, found between two adjacent vertebrae, consists of the outer anulus fibrosus and the inner nucleus pulposus. Adapted from (Moore et al., 2006).

(Farfan, 1973). Rehydration occurs in an unloaded posture, such as lying down. The interface between each vertebral body and the IVD is lined with articular hyaline cartilage, which is thinner on the superior margin (Oxland, 2016). The IVD is innervated, but only the outer and middle one third of the anulus.

From the vertebral arch arise seven processes; one spinous process, two transverse processes, plus two superior and two inferior processes of the ZPJ (Figure 4). The contact areas of a corresponding superior and inferior process are lined with articular hyaline cartilage, creating a right and left ZPJ (Moore et al., 2006). The ZPJs help to absorb compressive load, resist rotation in the lumbar spine, extension in the cervical spine and guide spinal column movements (Farfan, Cossette, Robertson, Wells, & Kraus, 1970; Przybyla, 2005). The relative ability of ZPJs to absorb load is related to their direction of alignment. In the lumbar spine, this is more in the sagittal plane, limiting rotation, while in the cervical spine, ZPJs are aligned more in the coronal plane and limit extension. Surrounding the articular hyaline cartilage is a synovial membrane that produces and retains synovial fluid for joint lubrication. The synovial membrane is supported by capsular ligaments. In the lumbar spine the posterior capsule consists of tight transverse fibres, while the superior and inferior capsule has lax fibres allowing facet displacement associated with flexion and extension, and the anterior capsule is replaced by the ligamentum flavum (Adams, Bogduk, Burton, & Dolan, 2006). In the cervical spine, the capsular ligaments are recognised as important stabilisers of the ZPJs (Ramieri, Domenicucci, Miscusi, & Costanzo, 2015).

Soft tissues like ligaments, capsules and the IVD play an important role in limiting spinal movement (Bogduk & Mercer, 2000; Mattucci, Moulton, Chandrashekar, & Cronin, 2012) and provide spinal column support (Figure 5). Ligaments are uniaxial structures connecting adjacent vertebrae and primarily consist of tight bundles of type 1 collagen, aligned in the direction to best resist load (Oxland, 2016). However, several named ligaments like the supraspinous ligament, anterior longitudinal ligament, interspinous (dorsal component) and intertransverse are not real ligaments, rather thickened membranes or extensions of tendinous attachment points (Adams et al., 2006). Ligament strength reduces with age in both the lumbar (Iida, Abumi, Kotani, & Kaneda, 2002) and cervical spine (Pintar, Yoganandan, & Voo, 1998).

All vertebrae, connected via IVDs, ZPJs and supported by ligamentous structures, represent a dynamic and mobile spinal column. However, the spinal column is not able to initiate, control or maintain posture by itself (Oxland, 2016). This function is controlled by the trunk muscles, comprising of spinal and abdominal muscles. Some spinal muscles span one vertebral segment while others span several. Abdominal muscles attach to the ribs, diaphragm and pelvis, assisting in spinal support and movement. Muscle function is controlled by neural networks linking them to the brain (Moore et al., 2006).

The interaction of the spinal structures to provide spinal stability has been classified into three interacting subsystems (Panjabi, 1992). The subsystems are passive (e.g., ligaments, IVD, capsules, vertebrae and ZPJ), active (e.g., muscles and tendons) and

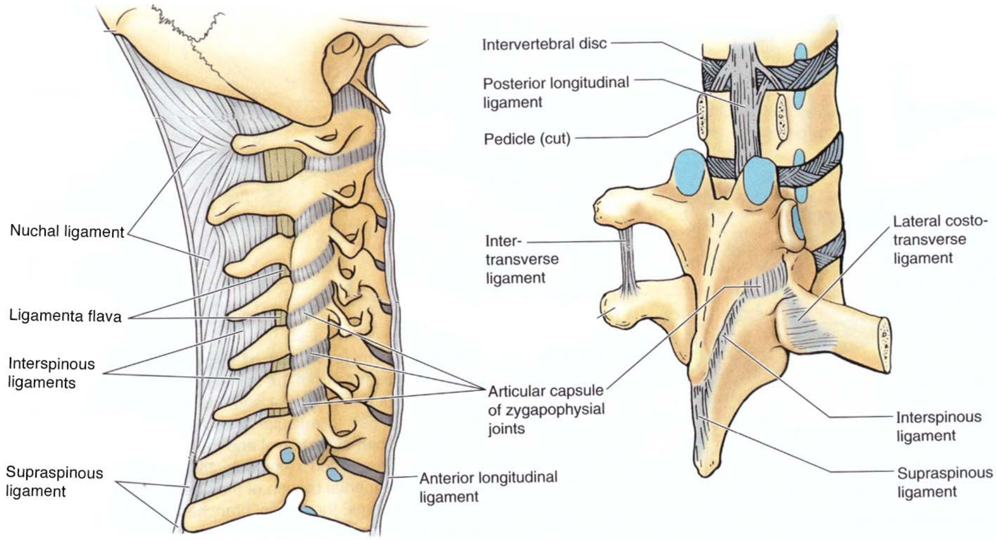

Figure 5. Spinal ligaments are an important support tissue, attaching bone to bone and limiting excessive movements. Reproduced with permission from Moore et al. (2006).

neural (e.g., nerves). The neural system receives information from receptors in the active and passive systems and initiates changes in the active subsystem to bring about stability, resisting loads around two to three times body weight. When the active and neural subsystems are not engaged, the load capacity or 'critical load' of the passive subsystem before it buckles has been determined as 20 N (2 kg) for the T1 to sacrum and 90 N (9 kg) for the L5 to sacrum specimens respectively (Panjabi, 1992).

2.2.3 Summary of Section 2.2 Spine Anatomy

The human spine is a flexible column providing structure and protection for the spinal cord. The basic building block of the spine is termed the functional spine unit, consisting of adjacent vertebrae and the associated IVD, ZPJs and ligaments. Static and dynamic posture of the human spine is initiated and controlled by the neuromuscular system. Without the active system involvement, passive structures have a much lower critical load capacity.

In Section 2.3 Spine Biomechanics, biomechanical loads that act on, and influence movements of the human spine and how spinal tissues resist these loads are reviewed. The effects of coupled movement and a low gravity environment on sleep postures will also be examined.

2.3 Spine Biomechanics

Many physical risk factors have been identified as having a strong relationship with spinal pain (Andersson, 1999; Kim, Wiest, Clark, Cook, & Horn, 2018). A large proportion of these spinal risk factors are biomechanical loads which commonly involve twisting, bending, lifting and whole body vibration (Hoogendoorn et al., 2000; Tiemessen, Hulshof, & Frings-Dresen, 2008). Not only is it important to consider the amount of load, but also the effect of the load as it is applied over time. It has been noted that low physical loads applied over time have a cumulative effect, potentially overloading collagenous tissues and causing the onset of symptoms (Kumar, 2001; Norman et al., 1998). In a 3 year prospective study, Hoogendoorn et al. (2000) examined the effects of physical load on the occurrence of low back pain (LBP). They observed an increased risk of LBP occurred in workers assuming a flexed posture greater than 30 degrees, for more than 10% of the time (OR = 1.22 (95% CI: 0.94, 1.57)), or rotation greater than 30 degrees for more than 10% of the time (OR = 1.28 (95% CI: 0.86, 1.90)), when compared to workers that spent 5% or less of their time in these postures. For these reasons, both biomechanical loads and the effect of load over time will be explored in this section.

2.3.1 Spinal Loads

There are three types of loads applied to the vertebral segments of the spinal column. The first is direct load, in which the load is applied along a single axis, most commonly the longitudinal axis and results in compression or elongation loads. The second is indirect load, due to the application of the load at a distance in which torque/leverage produces a rotation movement. The third is shear load, in which all parts of the tissue move equally in the same direction (Farfan, 1973).

2.3.1.1 Compression and Elongation

Loads applied along the longitudinal axis of the spinal column are termed compression and elongation (Figure 6). In vivo, some compressive loads are present due to the action of gravity on the upright spine, but the majority of compressive loads are generated by muscle contraction (Dolan et al., 1994; Kingma et al., 2001). Compressive loads were initially considered the cause of lumbar IVD herniation, until it was determined that the weakest part of a FSU to compression, was the vertebral end plate and not the posterior IVD (Farfan & Gracovetsky, 1984). Most in vitro biomechanical spinal research still examines the effect of compression, but now as a preload to simulate the effect of weight bearing in healthy or damaged FSUs (Adams, McMillan, Green, & Dolan, 1996; Miura, Panjabi, & Cripton, 2002; Pollintine, Dolan, Tobias, & Adams, 2004; Pollintine, Przybyla, et al., 2004). In healthy, unloaded lumbar cadaver FSUs, torsion is mostly limited by anular IVD fibres (Farfan et al., 1970; Krismer et al., 1996), but with the addition of compression, ZPJs play the major role in resisting torsion (Adams & Hutton, 1981). Spinal tolerance to compression reduces with age and degeneration (Sonoda, 1962) and as a consequence increased load is borne by the anular fibres and neural arch (Oxland, 2016).

The effect of movement in the sagittal plane (i.e., flexion and extension) on lumbar spinal tissues has been extensively examined. Flexion increases a passive elongation load in the posterior ligaments, increases an elastic load in muscles (McGill & Kippers, 1994), increases an anterior IVD compressive load and an associated anterior anulus bulge. Conversely, extension or a lordotic posture reduces posterior ligament elongation and increases neural arch compression, such that the proportion of compression on the posterior IVD reduces. The compressive load borne by the neural arch components, includes approximation of spinous process (Adams, Dolan, & Hutton, 1988) and the inferior margins of the ZPJ. Compressive loads at the inferior margin increase from 1% in a 'neutral' posture, to 16% in 2^0 of lordosis (Adams & Hutton, 1980). With IVD degeneration, the compressive load borne by the neural arch structures increases from a normal 20% up to 90%, providing a stress shielding of the degenerative IVD (Pollintine, Przybyla, et al., 2004). The effect of lumbar movement in the frontal plane (i.e., lateral bending) is less well researched. However, biomechanical extrapolation of information from the sagittal plane provides some indication of what loads are experienced. The lateral width of the lumbar IVD is approximately 50% greater than the anteroposterior width, so a sideways movement will cause a 50% greater deformation of the outer anulus fibres in comparison to what movements in the sagittal plane cause. Likewise, high concentration of compressive loads would be expected in the ipsilateral ZPJ and elongation in the contralateral capsule and ligaments (McNally, Adams, & Goodship, 1993).

In the upper cervical spine, flexion is limited by elongation in the posterior muscles and anterior compression of the submandibular tissues against the throat, with compression also occurring on the lateral facets of the atlas between the head and axis. Extension is limited by compression of the suboccipital musculature, impaction of the atlas against the odontoid process and the transverse and alar ligaments as they limit forward movement of the atlas. In the mid and lower cervical spine, flexion is limited by elongation in the posterior longitudinal ligament, ligamentum flavum, ZPJ capsules and interspinous ligaments. Extension is initially limited by

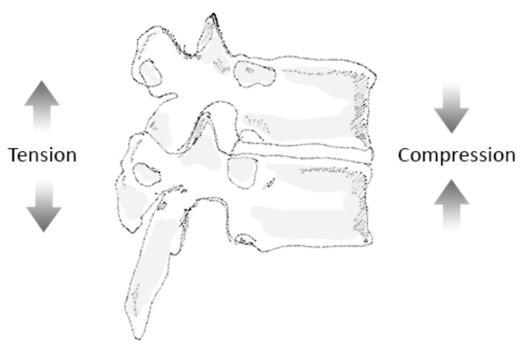

Figure 6. Loads of spinal compression and elongation. Adapted from (Moore et al., 2006)

Figure 7. Spinal loads of torque and shear. Adapted from (Moore et al., 2006)

elongation in the anterior longitudinal ligament, anulus fibrosus and ultimately by compression of the spinous process or laminae (Bogduk & Mercer, 2000). Tested as a whole cervical spinal unit, the interspinous ligaments played the major role in limiting flexion (48%) and the ZPJs played the major role in limiting extension (47%) (Przybyla, 2005).

2.3.1.2 Torque

Torque is an applied load that results in a rotatory movement (Figure 7). Following the recognition that compression wasn't a major contributor to lumbar IVD degeneration, research focus shifted to the effect of torque loads. Farfan (1973) noted in the case of the lumbar spine, that together the IVD, posterior and anterior longitudinal ligaments contributed 50% of the resistance load to rotation, the ipsilateral ZPJ articulation and contralateral ZPJ capsule 40%, and the supraspinous and interspinous ligaments contributed the remainder (Farfan, 1973). Tissues furthest from the point of rotation will experience the greatest loads. In the lumbar spine it was concluded that the tissues first to rupture during rotation, would be the supraspinous and interspinous ligaments (Farfan et al., 1970). The same author noted that with the addition of compression to an intact lumbar spinal segment, torque resistance increased by nearly 50% due to increased contribution from the ZPJs (Farfan et al., 1970). Conversely, this would indicate that in an unloaded lumbar spine such as in a recumbent position, the spine would receive less assistance from the ZPJs to resist rotatory movements and most of torque loads would be borne by viscoelastic tissues like ligaments. In the cervical spine, there are no anular fibres in the posterior portion of the IVD, rather a horizontal cleft which facilitates rotation. As a result of this anatomical variation and the oblique ZPJ alignment in the cervical spine, torque loads result in a much greater range of rotation in the cervical spine. Resistance to rotation in the cervical spine is provided by muscle contraction when conscious and passive structures, like ligaments and joint capsules when unconscious (Bogduk & Mercer, 2000; Przybyla, 2005).

2.3.1.3 Shear

The application of a shear load causes all parts of a tissue to move equally in the same direction and the resulting movement is termed translation (Figure 7). Anatomical orientation of spinal column ligaments and IVD collagen fibres means their role minimal in resisting shear loads. Muscle fibre orientation in the lumbar spine makes the erector spinae capable of resisting shear loads (Potvin, Norman, & McGill, 1991), but this is unlikely to occur while asleep or resting due to limited muscle activity.

Shear loads are largely attenuated by the bony vertebral arch (Cyron & Hutton, 1981). It has been demonstrated that cumulative exposure to the loads of compression and shear, predisposed the spine to injury and was a risk factor for spinal symptoms (Kumar, 1990). Importantly, these loads need not be large and there is the potential for small loads applied over longer periods of time, to become a source of tissue provocation and symptoms.

2.3.1.4 Effects of a Low Compression Environment

Movement of cervical and lumbar spine FSUs into flexion, extension and lateral bending are non-linear (see Section 2.3.4.1.3), while lumbar rotation and shear are near linear (Oxland, 2016). The largely non-linear behaviour led to the term 'neutral zone,' which is a region of free play. In the neutral zone, the FSU has low stiffness, high joint laxity and a higher sensitivity to injury (Oxland & Panjabi, 1992). The neutral zone is much larger in the cervical spine than the lumbar spine, due to morphology and increased range of motion, with approximately 7^{o} of movement available per segment in each plane (Wen, Lavaste, Santin, & Lassau, 1993).

When lying down, the two key compressive loads of muscle contraction and gravity are minimal, creating a low compression environment. The lack of compressive load on the spine when lying down, combined with the low stiffness and high joint laxity of the neutral zone, could leave the spine vulnerable to provocative loads caused by sustained or repeated non-supportive sleep postures. It is possible this effect would be greater in the cervical spine due to a larger neutral zone and greater reliance on passive restraints. It has been shown by Rohlmann, Petersen, Schwachmeyer, Graichen, and Bergmann (2012), that without isometric muscle contraction, lumbar spine load as measured by in vivo telemeterised vertebral body implants was nearly twice as high as compared to when an isometric muscle contraction was generated. Loads were assessed when moving from side lying to supine to side lying and side lying to prone to side lying, highlighting the important role muscle contraction has in absorbing loads that otherwise increase the load on passive structures, even when lying down.

2.3.1.5 Role of Coupled Motion

The concept of coupled motion was first explored in 1903, when it was observed in a lordotic lumbar spine that lateral bending induced an axial rotation in the contralateral direction (Lovett, 1903). When sleeping in right side lying on a firm mattress, support is mostly provided at the right hip and shoulder, resulting in a left lumbar lateral bending, due to the differences in the width of the waist and hip. Accordingly a right coupled rotation would occur (Gracovetsky, 1987). In the mid and lower cervical spine, it is generally agreed that a movement of lateral bending induces a coupled ipsilateral movement of rotation (White & Panjabi, 1990), but that the coupled motion between the second and third cervical vertebrae is in a contralateral direction (Bogduk & Mercer, 2000).

In addition to an increased cervical neutral zone and greater reliance on passive restraints, coupled motion may explain in part why waking symptoms of cervical pain can be more severe than lumbar pain (e.g. acute cervical torticollis). For example, when a person is lying on their right side, their lumbar spine is concave on the left in the frontal plane (Leilnahari et al., 2011), which will induce a coupled motion of trunk right rotation in the horizontal plane. With advancement of the top thigh into flexion, this will also create right lumbar rotation with the result being the two rotation loads are occurring in the same direction. The rotation load could be accentuated by a harder bed and by a greater waist to hip ratio, because both increase the degree of lateral bend and as a consequence, the degree of coupled rotation.

Coupled motion in the cervical spine is different because the cervical spine is usually resting on a pillow. When lying on the right side, if there is a lack of support provided by the pillow to the mid cervical spine, it will dip towards the mattress resulting in lateral bend to the left. Gordon and Grimmer-Somers (2010) reported that of all pillows evaluated, feather pillow users consistently report low levels of pillow comfort and sleep quality, which may have been due to the lack of cervical support provided by the feather pillows. A similar effect could occur when sleeping on a wedge or peanut pillow that pushed the head into lateral bending without supporting the neck. In the low and mid cervical spine, the coupled motion of rotation is towards the same side as lateral bending, which would result in left cervical rotation. In the example described of someone sleeping in right side lying, coupled motion of rotation to the right, starting in the lumbar spine will extend into the thoracic spine (Panjabi & Brand, 1976). However, the cervical spine coupled rotation in this example is to the left. Consequently, the coupled rotations of the lumbar and cervical spine in right side lying are in different directions, with the potential for tissue provocation and symptoms. With a greater range of motion and increased neutral zone when lying down, it is possible the cervical spine is more vulnerable than the lumbar spine. Using admission and discharge magnetic resonance imaging (MRI) scans, Gubin, Ulrich, Taschilkin, and Yalfimov (2009) noted in children presenting with waking symptoms of acute onset stiff neck, all had a wedge of swollen tissue represented by a high intensity signal between the second and third, or third and fourth cervical uncovertebral joints on the painful side. The authors proposed that this wedge represented an area of strangulated vascular tissue, which subsequently resolved on imaging with a correlated reduction in pain and normalisation of cervical movements.

2.3.2 Collagen Stress-Strain Response

Biological tissues like bone, cartilage, IVD, ligament or muscle, respond to applied external load in a similar way because of their common collagen building block. Collagen consists of tropocollagen molecules, that when grouped in ever larger quantities are progressively called collagen fibrils and then collagen fibres. Collagen fibres are bound together with proteoglycans and water (Adams et al., 2006). The stress-strain response of collagen fibres to load involves two features, material non-linearity and viscoelastic dissipation. A biological tissue is called non-linear because the stiffness of the collagen varies as the applied load changes and stiffness is a measure on how strongly a tissue resists being deformed (Adams et al., 2006).

2.3.2.1 Variability

2.3.2.1.1 Collagen Quality

Not all collagen is of the same biological quality or stiffness. As the biological quality varies, a tissue's ability to recover following load application will vary. Factors including age, gender, ethnicity, genetic disorders, previous injury and temperature influence the stiffness of collagen. Tissue elasticity is greatest at birth, declining rapidly through childhood and then at a slower rate in the low back (Iida et al., 2002) and neck (Mattucci et al., 2012) with increasing age. As a result of a sustained posture, tissues will also take longer to resume their normal length with increasing age and in the case of ligaments, their protective function will be limited until normal length is recovered. Females have greater elasticity than males across all age groups and as a result, increased creep has been documented in females (Solomonow, Baratta, et al., 2003). Epidemiology studies indicate hypermobility exists in less than 10% of the population (Larsson, Baum, & Mudholkar, 1987), but has been found to be higher in certain populations; 25.4% in Iraqi students (Al-Rawi, Al-Aszawi, & Al-Chalabi, 1985) and 43% in West Africans (Birrell, Adebajo, Hazleman, & Silman, 1994). Heritable connective tissue disorders like Marfan syndrome, Ehlers-Danlos syndrome and osteogenesis imperfecta all have increased laxity that impairs the protective functions of collagenous tissues (Simmonds & Keer, 2007). Collagenous tissues when injured have the ability to heal spontaneously, but the resultant scar tissue is almost always mechanically inferior and therefore less able to resist future loads (Mast, 1997). For example, previously injured IVDs were found to have an average torque load to failure of nearly half that of a normal IVD and that injured joints never regained more that 60% of normal torque strength (Farfan et al., 1970). Porcine lumbar ligaments, which have similar properties to human ligaments, when subjected to load have a strong temperature dependence (Hukins, Kirby, Sikoryn, Aspden, & Cox, 1990). When load is applied, peak loads increase as temperature decreases (Bass et al., 2007).

2.3.2.1.2 Sleep Posture and Spinal Load

Through the course of the night, changes in sleep posture will influence the amount of load spinal tissues are exposed to and for some individuals, theoretically the load may not reach their symptom threshold (Figure 8A), possibly due to a larger safety buffer as a result of higher quality collagen. An individual's safety buffer will be influenced by many factors, as previously discussed in Section 2.3.2.1.1. Theoretically, this means people with a smaller safety buffer but the same sleeping posture routine, will result in their symptom threshold being breached sooner. It should be noted that individuals have different sleep routines, however they mostly repeat them regularly from night to night (Chen, Guo, Shen, & Liu, 2013b; Deun et al., 2012; Kubota et al., 2003; Verhaert et al., 2009, August). In practical terms, not all sleep postures will subject spinal structures to the same load and as a result some sleep postures will cause higher loads, while other sleep postures a smaller load (Figure 8B). However, it is plausible that people with lower quality collagen are more likely to experience waking symptoms if sleeping in postures that increase spinal load. Sleep posture routines can also be influenced by sleep systems and this is discussed in Section 2.5.5.4.

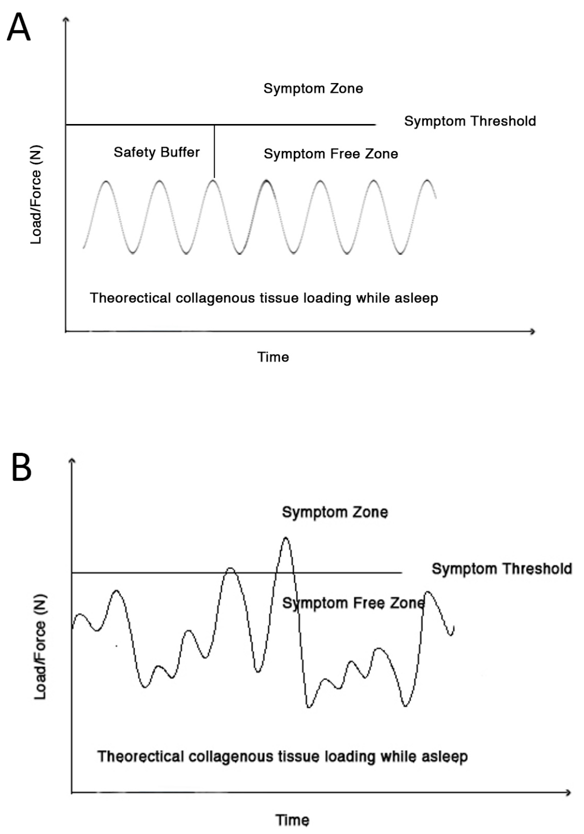

Figure 8. Biomechanical loading logic. A. Theoretical spinal load sequence experienced during sleep, staying below threshold and not resulting in symptoms. B. Practical spinal load sequence representing different sleep postures causing variable loads, with some passing through threshold and provoking symptoms. Adapted from (Marras, 2000).

2.3.2.2 Stress-Strain Curve

The stress-strain or load-deformation curve, is a graphical representation incorporating a stress load (e.g., applied load elongation/compression) and a strain response (e.g., being deformation) (Figure 9). The stress-strain curve is common to collagen fibres as well as tissues comprised of collagen fibres. It is typically shaped like an 'S', and divided into three parts; toe phase, elastic phase and plastic phase or point of failure (Figure 9). The stress-strain curve represents the ability of a tissue to resist deformation and relates to the stiffness of the tissue. Stiffness is calculated by the gradient of the curve, with stiffer tissues having a steeper gradient (Adams et al., 2006).

At rest, collagen fibres are wavy. This arrangement of fibres is termed crimp and with the application of load, a straightening effect occurs. This non-linear response occurs in the toe phase, where deformation of collagen fibres increases rapidly with minimal load, indicating the tissue has low stiffness. The transition from the toe phase to the elastic phase occurs around 3% collagen elongation and represents the maximal point of strain reached by most activities of daily living (Bogduk & Twomey, 1987). In testing single rat collagen fibres, crimp completely disappeared before 3% (95% CI: 2.0, 2.8%) strain was reached (Hansen, Weiss, & Barton, 2002). After the

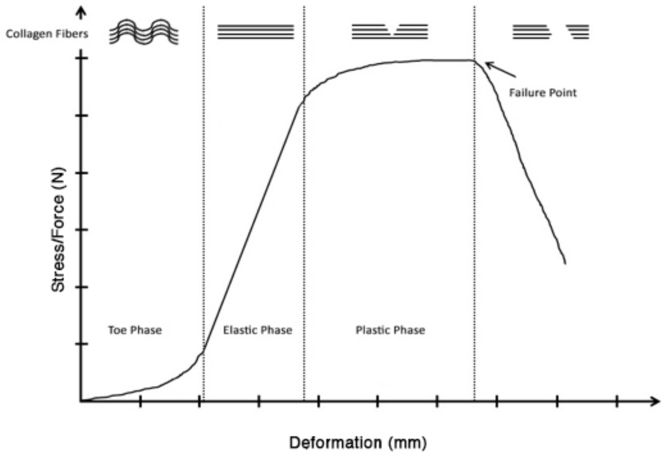

Figure 9. Collagen Stress Strain Curve. Under load, the stress–deformation relationship of a biological tissue (e.g., ligament) is initially nonlinear. The 'toe phase' in which rapid deformation occurs with increases in stress, indicates low stiffness. With additional load a linear region 'elastic phase' is reached in which stiffness is constant, and finally reduces in slope during the plastic phase, as the tissue stiffness begins to fail and finally reaching its ultimate strength and subsequent failure. Adapted from (PitchingNow, 2014).

point at which all crimp is removed (crimp extinction), further increases of load involve greater recruitment of stretched collagen fibres to resist the increasing mechanical strain (Adams et al., 2006). Stiffness at this point is constant and increases in load are matched by relative increases in deformation. In this elastic or linear phase, micro failure within the tissue begins to occur. Torsion strain tests on lumbar spine segments demonstrate the visual expression of fluids from the vertebral body in the early elastic phase (Farfan, 1973). With progression from the elastic into the final plastic phase, a significant number of the chemical bonds between collagen fibres have already broken. As a result, smaller increases of load will result in proportionally greater collagen elongation, until the point of ultimate failure (Thomopoulos & Genin, 2012).

2.3.2.3 Collagen Viscoelastic Properties

In addition to the mechanical non-linear response to load, collagen tissues display viscoelastic properties, that is having characteristics of both elastic solids and viscous fluids, which are time-dependent. For this reason, to fully understand the mechanical properties of collagenous tissues, in addition to the quantity of load, loading history and time also need to be considered. Typical features of viscoelastic materials include creep and hysteresis (Thomopoulos & Genin, 2012).

2.3.2.3.1 Creep

Creep is a time dependent deformation of tissue under constant load (Adams et al., 2006) (Figure 10). The reasons for creep are not conclusive, but are believed to be related to the re-arrangement of collagen fibres, proteoglycans, elastin, ground

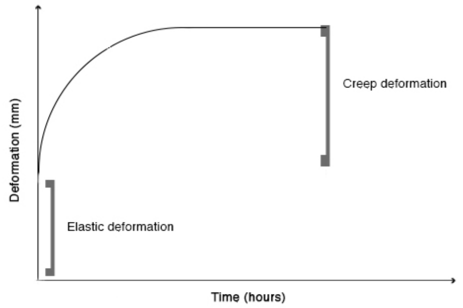

Figure 10. Creep curve for biological tissues. When a constant load is initially applied to a biological tissue, there is an immediate elastic deformation. If the constant load continues, further tissue deformation occurs as water is expelled from the tissue. This expulsion is initially rapid but gradually slows as an equilibrium is reached. Adapted (Adams et al., 2006).

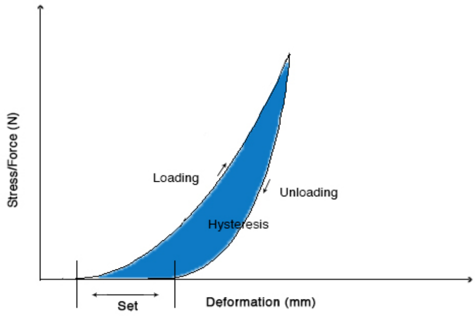

Figure 11. Stress-strain curve with hysteresis. A typical stress-strain curve of a biological tissue during the loading and unloading application of a non-damaging load. The blue shaded area represents the work undergone to deform the tissue. Adapted from (Adams et al., 2006).

substance and the displacement of water from the loaded tissue. The stress-strain curve represents the non-linear response of collagen to the application of increasing

load in a research context to the point of failure. However, in day to day activities this point is rarely reached. More commonly, the transition from toe to elastic phase is reached and maintained. For example, slumped sitting represents the end range of the spinal joints, resisted by collagenous ligaments and joint capsules. In asymptomatic individuals (N = 20, 10 females), full flexion range was found by Shin, D'souza, and Liu (2009) to be significantly different after 5 minutes (3.3% increase, p = .008) of standing forward flexion. In another study (N = 49, 24 females), it was reported after 10 minutes of long sitting flexion, there were also significant increases in flexion (males 2.0%, female 4.4%, p < .001) (Solomonow, Baratta, et al., 2003).

Studies examining creep have applied loads from several minutes to an hour and the response is different for different collagenous tissues. Sustained load to the supraspinous/interspinous lumbar ligaments, results in rapid elongation within minutes (Yahia, Audet, & Drouin, 1991). However with sustained loads applied to IVDs, creep occurs over several hours as fluid volumes are redistributed and equilibrium is reached (McMillan, Garbutt, & Adams, 1996). Practically, in the case of spinal flexion this means that sustained loads into flexion will proportionally have a greater effect on the posterior longitudinal and interspinous ligaments, with the result being that the protective capacity of these ligaments is reduced.

While creep is usually associated with sustained load, it also occurs with repeated movements. Repeated mechanical loading of the spine is believed to result in the development of cumulative trauma disorder (Marras, 2000). Using feline lumbar spines exposed to 10 minutes sustained flexion followed by 10 minutes rest and repeated three times, Solomonow, Zhou, Baratta, and Burger (2003) found that viscoelastic tissues did not fully recover under an equal ratio of load and rest, nor after a period of 7 hours of mechanical rest. They found muscle spasms and

muscle hyperexcitabilities were associated with creep in the lumbar viscoelastic tissues. Creep is not just the result of muscle fatigue. In cadaveric spines subjected to sustained or repeated loads, it was found that 5 minutes of sustained full flexion reduced resistance to further flexion by 42%. When 100 repeated full flexion movements were applied in the same time frame, resistance to further flexion was reduced by 17% (Adams & Dolan, 1996). It would seem that following a period of sustained or repeated loadings, collagenous tissues experience creep that may require a rest ratio greater than the load ratio and that in an in vivo situation, creep is associated with muscle hyperexcitability and spasm.

2.3.2.3.2 Hysteresis

As a biological tissue is loaded, the response of that tissue is characterised by a stress-strain curve. However, during unloading, tissue undergoes a different curve, such that restoration of the tissue's original length is slower than the initial loading time (Figure 11). A perfectly elastic tissue would immediately return to the original position, however biological tissues are not perfectly elastic and energy is lost in the form of heat between load application and load removal (Adams et al., 2006). Displaced water, re-arranged collagen fibres and proteoglycans and the possible breakage of chemical bonds, all require energy and time to reverse and recover. This difference in tissue behaviour between loading and unloading is called hysteresis, and the amount of difference is called a set (Figure 11).

2.3.2.3.3 Fatigue Failure

Structures can be damaged as a result of the application of a high load once, or much smaller loads applied many times (Figure 12). Fatigue failure occurs when

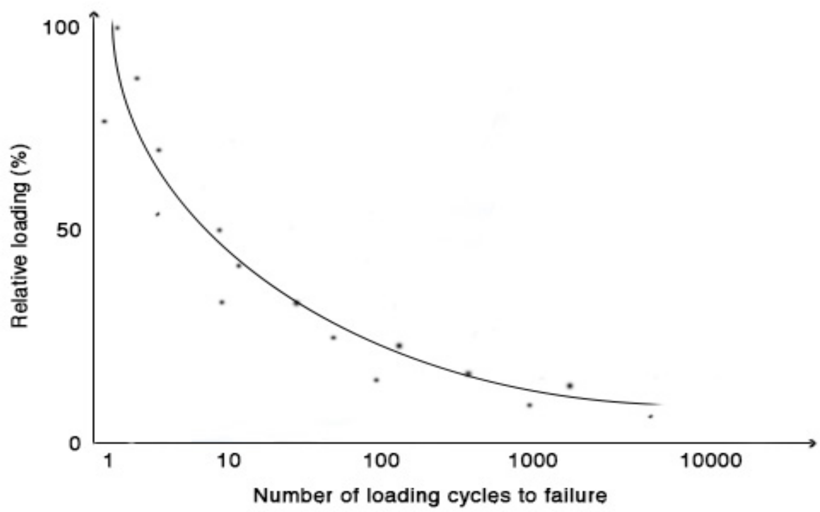

Figure 12. A graph of fatigue failure of collagen tissue under repeated loading. Adapted from (Adams et al., 2006)

repeated application of small loads results in tissue micro damage (i.e., small plastic deformations), too small to be detected if only applied once. However, the repeated application results in an accumulation of load that can cause complete structure failure, even though the final applied load was small (Adams et al., 2006; Kumar, 1990, 2001). Each individual has a repeated routine of sleep postures, resulting in common tissue loading each night. It has been proposed that chronic tendon stress (i.e., compression), as a result of sleeping with the arm abducted, could be responsible for chronic tendinopathy of the rotator cuff, nocturnal shoulder pain and possibly spontaneous rotator cuff rupture (Gorski, 2018).

2.3.2.3.4 Clinical Relevance of Creep, Hysteresis and Fatigue Failure

The biomechanical concepts of creep, hysteresis and fatigue failure following sustained or repeated cycles of loading and unloading, have important clinical consequences with respect to sleep postures. While creep is a reversible and an entirely normal physiological response to load, repeated and/or sustained loads do result in tissue changes like hysteresis and fatigue failure, and have been associated with abnormal muscle activity. From a young age, humans develop and consolidate a regular routine of repeated sleeping postures throughout the night, involving both sustained and repeated postures. Authors have proposed that the repeated application of low loads over time to the spine, can have a cumulative effect, overload collagenous tissues (Kumar, 2001; Marras, 2000) and contribute to injuries (Gorski, 2018). It has been noted, that participants over 18 years of age, on average change their posture between 2.1 and 3.6 times per hour (De Koninck et al., 1992). This indicates that sleep postures are commonly sustained for periods of greater than 15 minutes, a time frame in which in vitro (Yahia et al., 1991) and in vivo (Solomonow, Baratta, et al., 2003) viscoelastic spinal collagenous tissue creep has been demonstrated.

Some sleep postures will be supportive of collagenous spinal tissues, while others will increase spinal tissue loading. Relationships between biomechanical creep and spinal symptoms in relation to sustained and repeated low loading, have been extensively explored using in vivo designs with healthy human and feline groups (Solomonow, 2012; Solomonow, Baratta, et al., 2003; Solomonow, Zhou, et al., 2003; Solomonow, Zhou, Lu, & King, 2012). Under sustained rotation loading for 10 minutes in sitting, viscoelastic creep was demonstrated in vivo in asymptomatic males (N = 16) (Shan et al., 2013). In addition to observing a significant increase in trunk axial rotation (M = 10.50, SD = 5.2, p < .001), the authors also reported a significant increase in lumbar pain measured using a visual analogue scale (VAS) (M = 45.1, SD 10.6, p < .001). In another experiment, asymptomatic human participants remained in long sitting for 10 minutes and more than 50% of participants consequently developed muscle spasms (Solomonow, Baratta, et al., 2003). The authors suggested this was indicative of micro-damage to viscoelastic tissues and explored this relationship in feline spines. After calibration, feline spines were exposed to 10 minutes of sustained flexion (20 and 60 Nm), followed by 10 minutes of unloaded rest which was repeated six times after which the spines were rested for 7 hours (Solomonow, 2012). Ligaments were harvested from loaded and non-loaded spinal segments after the recovery period. The author reported significant increases in a range of pro-inflammatory chemicals expressed during the recovery period, indicating acute inflammation and tissue damage in ligaments subjected to the cyclic loading, compared with the control ligaments from the same spine. The author also noted significant increases in muscle activity during the recovery period, which increased with increases in load, increases in the number of repetitions, and decreased during rest periods.

2.3.3 Summary of Section 2.3 Spine Biomechanics

In Section 2.3. Spine Biomechanics, the types of loads acting on the human spinal column and how collagen containing tissues like ligaments, IVDs and capsules, undergo predictable mechanical and viscoelastic changes in response to a single sustained or repeated load were discussed. Not all collagenous tissues are equal in biological quality, with many factors influencing their elastic stiffness including age, gender, genetics, ethnicity, temperature and prior injury. This means that under similar load situations, collagenous tissues may respond differently. When recumbent, there is less gravity compression and when asleep, less muscle compression, with the overall result being that the normal restraints to elongation loads are less effective and loads on collagenous tissues increase. This reduction in compression leaves viscoelastic tissues vulnerable to sustained and/or repeated loading. Sustained and/or repeated loads causing 3% or greater elongation, have resulted in collagenous tissue micro-damage. Micro-damage has been associated with an increased expression of pro-inflammatory cytokines in animal studies and muscle spasms in both human and animal studies. The presence of pro-inflammatory cytokines, would likely result in the clinical presence of symptoms like pain, stiffness and bothersomeness. Quality of sleep may as a result be also impacted.

In the next section of Chapter 2., Spine Symptoms, the types of clinical symptoms and specific anatomical structures with the potential to generate spinal symptoms are discussed.

2.4 Spine Symptoms

2.4.1 Types of Clinical Spine Symptoms

A range of symptoms (e.g., pain, stiffness and bothersomeness) and quality of sleep have been used as clinical measures to evaluate spinal load. Researchers collecting self-reported waking cervical symptoms of pain, stiffness and quality of sleep at two time points 18 months apart, found that self-report was consistent for healthy adults (Gordon & Grimmer-Sommers, 2011). Another study by the same authors found participants that woke with one symptom (e.g., pain), were significantly more likely to wake with a second symptom (e.g., stiffness) (OR 19.2 (95% CI: 12.5, 29.9)) (Gordon et al., 2002). More recently the concept of bothersomeness of pain has also been studied in relation to spinal symptoms (Cho et al., 2013; Dunn & Croft, 2005; Stewart, Maher, Refshauge, Herbert, et al., 2007).

2.4.1.1 Pain

Pain is defined by the International Association for the Study of Pain, as an unpleasant sensory and emotional experience associated with actual or potential tissue damage (PainAustralia, 2017). The lifetime prevalence of spinal pain in the general population has been estimated as 66%, with 44% in the cervical spine and 56% in the lumbar spine (Linton, Hellsing, & Halldén, 1998). Others have reported a one-year point prevalence in the general population ranging from 30% to 50% for cervical pain (Hogg-Johnson et al., 2008) and a lifetime prevalence of 66% for cervical pain (Rubin, 2007). A one-year point prevalence of 20% to 60% and a 60% to 80% lifetime prevalence of non-specific lumbar pain has been reported in industrialised countries (Adams et al., 2006; Hoy et al., 2012). Both cervical and lumbar pain peak in mid-life, are more common in women than men, have increased markedly in incidence and disability over the past 25 years and are expected to continue rising (Hurwitz et al., 2018). Cervical and lumbar pain contribute to large economic and societal costs and are major sources of work disability (Ekman, Johnell, & Lidgren, 2005; Wasiak, Kim, & Pransky, 2006). Research indicates that remissions in symptoms are temporary rather than permanent (Croft et al., 2001; Hestbaek, Leboeuf-Yde, Kyvik, & Manniche, 2006) and chronic cervical and lumbar pain develops in 25% to 60% of patients (Manchikanti, Singh, Datta, Cohen, & Hirsch, 2009).

Risk factors for spinal pain have been grouped into personal factors; age, gender, socioeconomic status, tobacco use, body mass index (BMI), psychological factors like depression and physical risk factors (Rubin, 2007). Physical risk factors for lumbar pain include sitting (Andersson, 1981; Kelsey & White, 1980; Magora, 1974; Williams, Hawley, McKenzie, & van Wijmen, 1991), bending (Boissonnault & Di Fabio, 1996), lifting and vibration (Bovenzi & Hulshof, 1999; Magnusson, Pope, Wilder, & Areskoug, 1996; Teschke, Nicol, Davies, & Ju, 1999). Physical risk factors for cervical pain include trauma (Holly et al., 2002), cervical flexion (Grimmer, 1996; Hanten, Olson, Russell, Lucio, & Campbell, 2000), arm load, arm posture, duration of sitting, twisting of the trunk, hand-arm vibration and workplace design (Ariens,

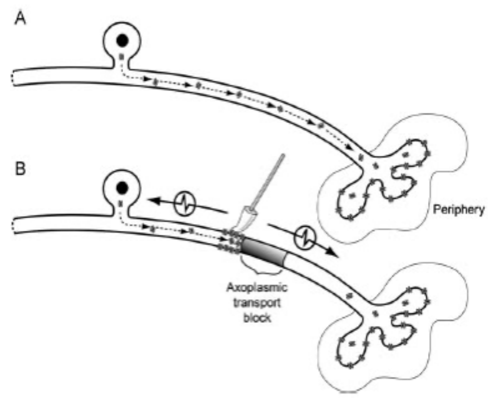

Figure 13. Neural Mechanical Sensitivity. A. Components required for mechanical sensitivity are transported from the cell body of a single C-fibre neuron to the periphery for insertion at the terminals. B. Blocking axoplasmic transport leads to the accumulation and insertion of mechanosensitive components proximal to the site of axoplasmic blockade. Mechanical stimulation of the axon membrane therefore becomes an effective stimulus to generate action potentials that pass in both directions along the axon (denoted by arrows) (Dilley & Bove, 2008a).

Van Mechelen, Bongers, Bouter, & Van Der Wal, 2000). These physical risk factors for cervical and lumbar pain all have a common theme, they relate to erect, day-time postures.

Nociceptive stimuli are conveyed by small diameter (myelinated and unmyelinated) nerve fibres in response to noxious stimuli in their target tissue. Nerves themselves do not normally generate impulse signals, rather signals arise from target tissues and nerves convey the high threshold impulse. However, it has been demonstrated that the nervi nervorum of nerves can generate pain signals without any nerve damage or loss of function, if the nerve is inflamed (Bove, Ransil, Lin, & Leem, 2003) or if the axoplasmic flow in the nerve is restricted (Dilley & Bove, 2008a) and then subjected to mechanical stimulation (Figure 13). Pro-inflammatory chemicals have been identified in viscoelastic tissues subjected to creep as a result of exposure to sustained and/or repeated low load as discussed in Section 2.3.2.3.3. In addition to viscoelastic tissues being damaged as a result of creep, released pro-inflammatory chemicals may also sensitise adjoining neural structures and cause the generation of pain signals.

2.4.1.2 Stiffness

Stiffness is defined in biomechanics as the rigidity of a tissue, or how well a tissue is able to resist deformation in response to an applied load (Adams et al., 2006). Conversely the more pliable a tissue, the less stiffness it exhibits. Subjectively, stiffness is the experience of limited movement. Prior authors conducted two complementary experiments, measuring the lumbar range of flexion in healthy participants (N = 21) and equating it to changing IVD height, observed when testing whole lumbar cadaveric functional spinal units (N = 19). They measured participants' spinal flexion morning and night and noted an increase in flexion (M = 15^0) as the day progressed. In the cadaver experiment, 6 hours of creep compression loading was applied to represent gravity. Whole of lumbar spine flexion was measured before and after the 6 hours creep loading and the authors noted an increase in flexion (*M* = 22.5^0). The participant's improvements in lumbar flexion were attributed to a reduced IVD volume and subsequent approximation of the vertebrae. With vertebral approximation, the posterior anular fibres and posterior ligaments were relatively relaxed, enabling a greater range of flexion. The authors' conclusion was that forward bending movements in the early morning, subject the lumbar spine to higher bending stresses as a result of increased tissue stiffness and make the lumbar IVD and ligaments more vulnerable to injury (Adams, Dolan, & Hutton, 1987). This has been acknowledged by others (Marras, 2000) and limiting morning flexion has been shown to reduce LBP onset (Snook, Webster, McGorry, Fogleman, & McCann, 1998). Two other important points are worth noting when focusing on IVD volume and spine stiffness. Firstly, the temporal rate of spine height change is not uniform, with a rapid 26% whole of spine height loss occurring in the first 1 hour (Krag, Cohen, Haugh, & Pope, 1990) and 63% within the first 2 hours of assuming an upright posture (Krag et al., 1990). Secondly, the change in range of movement is not the same for different movements. In healthy participants aged 18 to 22 years of age (*N* = 12), it was reported that after 8 hours of lying down, there was a significant reduction in spine flexion but not rotation or extension (Wing, Tsang, Gagnon, Susak, & Gagnon, 1992).

Increased spinal stiffness has also been associated with augmented muscle activity in participants with LBP (Arendt-Nielsen, Graven-Nielsen, Svarrer, & Svensson, 1996; Radebold, Cholewicki, Panjabi, & Patel, 2000). For example, it was reported that compared to healthy participants, participants with recurrent LBP demonstrated increased spinal stiffness into flexion, when subjected to spinal perturbations (Hodges, van den Hoorn, Dawson, & Cholewicki, 2009). The increased muscle activity may be a protective reaction to support injured bony and soft tissues (Panjabi, 1992) or to prevent further injury (van Dieën, Cholewicki, & Radebold, 2003). Further, the perceived threat of pain may also increase muscle activity and spinal stiffness (Hodges et al., 2009).

Cervical stiffness produced during the night or not relieved on waking, is the most common complaint reported by healthy participants sleeping on their own pillow (Gordon & Grimmer-Somers, 2010). These subjective reports of waking cervical stiffness are clinically observed to be greatest first thing on waking and to improve in most people over the next few hours (Gordon et al., 2002). This self-reported stiffness could be due to an increased IVD volume as described before, or it could be augmented muscle activity secondary to pain caused by nocturnal postural stress (Gordon et al., 2002). Measuring in vivo active and passive movements of the cervical (Dvorak, Antinnes, Panjabi, Loustalot, & Bonomo, 1992) and lumbar spine (Dvorak, Vajda, Grob, & Panjabi, 1995), researchers noted that all active spinal movements were less than their corresponding passive movement, movements were less first thing in the morning and that older participants had less range of movement than younger participants. However, in vitro examinations of FSUs with advanced lumbar disc degeneration, have shown only slight decreases in flexion, extension and lateral bending, with slight increases in rotation, when compared with spinal units exhibiting minimal disc degeneration (Kettler, Rohlmann, Ring, Mack, & Wilke, 2011; Mimura et al., 1994). As a result of the above findings, Oxland (2016) believes the reduced in vivo passive range and reduced range with increasing age, may be due to augmented protective muscular activity, rather than a loss of passive spinal column flexibility due to disc degeneration. Such protective neuromuscular activity, has been observed in feline spines subjected to sustained and repeated low loads (Solomonow, 2012; Solomonow, Zhou, et al., 2003) and also in in vivo experiments on healthy humans (Solomonow, Baratta, et al., 2003).

In summary, it is possible that the experience of morning stiffness on flexion, is due to an increased IVD volume with an associated increased elongation in the posterior anular IVD fibres and the posterior ligaments, and/or a protective neuromuscular response triggered by the release of pro-inflammatory chemicals from damaged spinal tissues.

2.4.1.3 Bothersomeness

The term 'bother' was originally used to assess symptom severity in patients with asthma (e.g., "how much bother does wheezing cause?") (Steen et al., 1994, p. 309) and then adapted for musculoskeletal conditions. Bothersomeness was included in a study analysing health outcome measures in patients with sciatica (e.g., "bothersomeness of leg pain" and scored from zero (not bothersome) to six (extremely bothersome)) (Patrick et al., 1995). A sciatic bothersomeness index, was created by summing together the bothersomness of four factors; leg pain, leg paraesthesia, leg weakness and back or leg pain while sitting, creating a maximin score of 24. The summed bothersome index was found to have good internal consistency, construct validity and was responsive to clinical changes (Patrick et al., 1995). An international group of back pain researchers included bothersomeness in a list of recommended outcome measures, to be considered by researchers and clinicians investigating LBP (Deyo et al., 1998, p. 2005). They recommended using the phrase "During the past week, how bothersome have the following symptoms been? a) Low back pain, b) Leg pain (sciatica)". In this context bothersomeness was scored from one (not at all bothersome) to five (extremely bothersome). As part of a randomised clinical trial examining participants with whiplash associated disorder, a range of pain measures were evaluated which included pain intensity, pain bothersomeness and the SF36 bodily pain sore (Stewart, Maher, Refshauge, Bogduk, & Nicholas, 2007). Using a numerical rating scale (NRS), pain bothersomeness was scored from 0 to 10 and was found to be significantly more responsive than the pain intensity NRS, VAS and the SF36 bodily pain score. Most recently bothersomeness was used in a study examining the effect of acupuncture on chronic low back pain (cLBP). Pain intensity and bothersomeness were used in a VAS format (i.e., 0 is the absence of bothersomeness and 10, the worst bothersomeness imaginable). In this study the term bothersomeness was used, not pain bothersomeness and the bothersomeness VAS was chosen by the authors as the primary outcome measure, to "understand the impact of cLBP on the patients' life" (Cho et al., 2013, p. 551) and pain intensity VAS was the secondary outcome. The use of the term bothersomeness, which evolved from use in respiratory research to use in musculoskeletal research as an outcome measure, would seem to provide additional data to that provided by other more commonly used outcome measures like pain VAS and the SF36 bodily pain score.

2.4.1.4 Sleep Quality

The links between sleep quality (i.e., initiation and maintenance of sleep) and spinal symptoms like pain, have been extensively explored in the past few decades. Essentially, poor quality sleep increases susceptibility to episodes, severity and sensitivity of pain (Bigatti, Hernandez, Cronan, & Rand, 2008; Simpson, Scott-Sutherland, Gautam, Sethna, & Haack, 2018). Consequently in the field of chronic pain, reduced sleep quality is recognised as an indicator of centralised hypersensitivity (Sterling & Kenardy, 2008) and post-traumatic stress syndrome (Stam, 2007). Although the direction of causality is not confirmed and the relationship between sleep quality and pain has historically been considered bidirectional, several lines of new research point to sleep quality as being the antecedent factor (Finan et al., 2013). This is indicated in the insomnia research literature, where poor sleep quality is predictive of new pain onsets and exacerbation of existing pain (Onen, Alloui, Gross, Eschallier, & Dubray, 2001; Sivertsen et al., 2014) in patients with fibromyalgia syndrome (Bigatti et al., 2008), temporomandibular joint pain (Quartana, Wickwire, Klick, Grace, & Smith, 2010), and with a range of chronic musculoskeletal presentations (Koffel et al., 2016; Tang, Goodchild, Sanborn, Howard, & Salkovskis, 2012). There is also growing awareness of associations between poor sleep quality and both regional and widespread chronic musculoskeletal pain in adolescents (Harrison et al., 2014). Also, in adolescents, predictive links between poor sleep quality and cervical and lumbar pain in females have been established, specifically, that poor quality sleep is an independent risk factor for cervical and lumbar pain (Auvinen et al., 2010; El-Metwally et al., 2004). Poor quality sleep is also linked with depression (Baglioni et al., 2011), motor vehicle accidents (Philip et al., 2010), work place accidents (Daley et al., 2009) and large economic costs to society (Economics, 2011).

Specific sleep quality factors that influence pain have been identified. In a large, cross-sectional, population-based cohort, sleep onset latency, sleep efficiency, frequency and severity of insomnia, but not sleep duration were significantly associated with pain sensitivity (Sivertsen et al., 2015). Similarly, it was reported that actigraphically measured sleep efficiency, reliably predicted next day pain reports in a group of chronic pain participants with insomnia (Tang et al., 2012). In both studies, sleep efficiency was identified as being significantly influential on pain sensitivity. Sleep efficiency is defined as the ratio of time spent asleep, compared to the total time spent in bed. For this reason, factors that contribute to decreasing an individual’s ability to fall asleep and maintain an asleep state, for example spinal pain, could be considered factors that might decrease sleep efficiency and therefore sleep quality.

In early research examining quality of sleep and involving self-reported good and poor sleepers, it was noted that poor sleepers had more awakenings and were awake longer (De Koninck et al., 1983). The researchers concluded that sleep posture constituted an important variable and may be related to quality of sleep.

Associations between sleep posture and sleep quality have been noted in patients with medical conditions like positional obstructive sleep apnoea (OSA), (recommended to avoid supine to reduce apnoeic events) (Cartwright, Ristanovic, Diaz, Caldarelli, & Alder, 1991), heart burn/indigestion (recommended to sleep upright to reduce gastric reflux), asthma (recommended to avoid right side lying as it increases vagal tone) (Backon & Kullok, 1990), those with spinal symptoms, like lumbar spinal stenosis (recommended to avoid prone) (Goldman, 2005) and waking cervicothoracic symptoms (recommended to avoid upright and prone) (Gordon et al., 2007a). It seems plausible, that aspects of sleep quality (e.g., sleep efficiency) could be associated with sleep posture and that poor sleep quality influences a range of musculoskeletal conditions associated with spinal symptoms.

2.4.2 Potential Sources of Spinal Symptoms

It has been recognised that biological structures can be damaged through the application of a single high load or repeated low loads (Kumar, 1990). See Section 2.3.2.3.4. In a minimal compression environment, loads applied to the spine are primarily limited by soft-collagenous structures like IVDs (Farfan et al., 1970; Krismer et al., 1996), ligaments, ZPJ capsules and the elastic component of muscles, while hard collagenous structures like ZPJs play a minor role (Adams & Hutton, 1981). Experimental studies that involve the application of noxious stimuli to ZPJs (Bogduk & Marsland, 1988; Schwarzer, Wang, Bogduk, McNaught, & Laurent, 1995), interspinous ligaments (Kellgren, 1939), muscles (Feinstein, Langton, Jameson, & Schiller, 1954; Travell & Simon, 1999) and the IVDs of asymptomatic and symptomatic participants (Saifuddin, Braithwaite, White, Taylor, & Renton, 1998), have demonstrated the ability for all of these tissues to produce local and referred symptoms. All structures discussed in this section, are innervated by nociceptors (Coppes, Marani, Thomeer, & Groen, 1997; Giles & Harvey, 1987; Korkala, Grönblad, Liesi, & Karaharju, 1985) and are therefore sensitive to noxious stimuli.

2.4.2.1 Intervertebral Disc

Two mechanisms have been associated with IVD injury and degeneration. Firstly, excessive mechanical loads and secondly, impaired nutritional supply.

2.4.2.1.1 Excessive Mechanical Load

A large amount of whole spine loading and mechanical stability research was performed leading up to 1990 (Oxland, 2016). Prior authors have noted that a torsion load is applied to the spine in asymmetrical side lying postures (Gracovetsky, 1987; Verhaert et al., 2012). Subject to the conditions of sustained load as discussed in Section 2.3.2.3, this would result in viscoelastic creep in spinal tissues (Panjabi, Krag, White, & Southwick, 1977) and two possible outcomes have been proposed. Firstly, that the motion segment rotates further and increases the load on the anulus fibrosus with possible damage (Farfan & Gracovetsky, 1984), or secondly, the motion segment does not rotate further and additional load is borne by the compressed ZPJ (White & Panjabi, 1978). For example, one author found that the majority of torque load was resisted by the IVD with the remainder resisted by the compressed ZPJs (Farfan, 1973). The author noted there was no gross injury to the vertebral body or ZPJs, however, extensive peripheral anulus fibrosus separations were identified. Other researchers found that the greatest resistance to torque was by the ZPJ and the anular fibres of the IVD were minimally involved (Adams & Hutton, 1981). It is likely that degrees of both occur, with the dominant tissue resisting the applied torque varying according to age and degree of pre-compressive load. In the former study, only two of the 12 specimens were 37 years of age or younger and no preload was applied, while in the later, 12 of the 25 specimens were 37 years or younger and compression preload was applied. It has been noted with increasing age, there is a reduction in ZPJ articular cartilage thickness and subsequently a greater range of movement occurs before ZPJ compression limits rotation (Adams & Hutton, 1981). In this case the soft tissues are resisting more load than the ZPJ. When observing FSUs, motion decreases under compressive load which is thought to occur because of increased ZPJ facet approximation (Oxland, 2016). Other researchers who examined cadaveric spines (M = 30 years), applied torque loads without compression and noted these loads were primarily resisted by anular IVD fibres resulting in peripheral rim and circumferential lesions (Krismer et al., 1996). In summary, in older aged specimens and in specimens without compression, a greater proportion of torque load is resisted by the IVD anular fibres and less by the ZPJs. It follows that when recumbent, whether young or old in age, a greater proportion of torsion load is likely to be attenuated by the IVD because of the minimal compression environment.

Small fissures in the anulus fibrosus near the uncovertebral joints in the cervical spine have been noted in children as young as 9 years old (Bogduk & Mercer, 2000). It is in this anatomical area that children who developed acute stiff neck during prolonged sleep or sudden head movement, were found to have localised irritated tissues on MRI (Gubin et al., 2009). Resolution of neck symptoms and improvement in range of motion occurred concurrently with normalisation of MRI findings. With increasing age these tears progress medially and increase in size so that by the third decade, a horizontal cleft spans from each uncovertebral joint, eliminating the anulus fibrosus posteriorly and facilitating cervical rotation (Bogduk & Mercer, 2000). It is possible that a sudden or sustained torsion load could provoke these pain sensitive tissues in the cervical IVD.

2.4.2.1.2 Impaired Nutrition

Lacking a direct blood supply, the IVD is largely avascular and relies on nutrition diffusing from the superficial anular fibres and the vascular tissues of the vertebral end plate (Adams et al., 2006). The supply of nutrition to the IVD is considered barely adequate at the best of times (Maroudas, Stockwell, Nachemson, & Urban, 1975; Urban, Holm, Maroudas, & Nachemson, 1982) and impaired nutritional supply has been associated with cell death and degenerative changes in IVDs (Bibby, Fairbank, Urban, & Urban, 2002; Horner & Urban, 2001; Nachemson, Lewin, Maroudas, & Freeman, 1970).

During the day, gravity, muscle contraction and movements associated with upright postures, produce compressive loads that push fluids out of the IVD at a rate of approximately 20% over 6 hours (McMillan et al., 1996). Fluid movement occurs via the vertebral end plate and the peripheral anular fibres. When lying down, the diurnal pressure gradient is reversed and fluid along with nutrients diffuse back into the IVD. The rate of diffusion of nutrients into an area of the IVD is influenced by the distance to the nearest blood vessel. This distance is called the diffusion path length. Flexion postures increase anterior IVD compression and thickening (0.1 mm/degree of movement), while at the same time stretching and thinning occurs in the posterior anulus (Stokes, 1988). Compared to upright standing extension or lumbar lordosis, flexion stretches and thins the posterior anulus by 60% (Pearcy & Tibrewal, 1984). This reduces the diffusion path length by thinning the posterior IVD and enhances nutrient supply into the posterior region (Adams & Hutton, 1986). However, sleeping postures that involve lordosis will potentially have a negative effect on the pressure diffusion gradient of the posterior IVD. Spinal extension or a lordotic posture, increases the diffusion path length due to a thickened posterior IVD with a resultant reduction in nutrient inflow. Further, when comparing IVD collagen cells in culture that were subjected to either static load or cyclic load, it was noted that collagen and proteoglycan synthesis were inhibited under static load (Ishihara, McNally, Urban, & Hall, 1996). As a consequence of sustained postures in extension, it is biologically plausible that the optimal flow of nutrients into the IVD will be reduced, with potentially important long-term consequences, such as cell death and IVD degeneration (Bibby et al., 2002; Horner & Urban, 2001; Nachemson et al., 1970).

2.4.2.2 Zygapophyseal Joints

Zygapophyseal joints play an important role in guiding and limiting spinal movements and are therefore a potential source of cervical and lumbar pain. Articular hyaline cartilage covers the surface of ZPJs and is a poroelastic material with a high-water content, enabling it to distribute loads evenly. After the application of a short duration load, poroelastic tissues rebound quickly (elastic component), but when loaded slowly, ZPJs experience creep (porous component) (Adams et al., 2006). Healthy articular cartilage has no blood or nerve supply, preventing it from being a source of symptoms (Adams et al., 2006). However, in situations of ZPJ degeneration it has been determined that subchondral bone contains substance P neurons and is therefore capable of producing pain (Beaman, Graziano, Glover, Wojtys, & Chang, 1993). As noted in Section 2.4.1.1, there is an important interplay between the roles played by the IVD and ZPJs in limiting torsion. Generally, it would seem the ZPJ plays a more important role in limiting movement when compression is present (Adams & Hutton, 1981; Liu et al., 1985), while the IVD has a more important role in a low compression environment (Farfan et al., 1970; Krismer et al., 1996). However, ZPJs also play an important role in limiting anterior shear and extension (Adams et al., 2006). This ability to ameliorate anterior shear in the lumbar spine is better achieved by ZPJs with a frontal orientation (Sharma, Langrana, & Rodriguez, 1995) while in the cervical spine, it has been reported the ZPJs limit 48% of extension load (Przybyla, 2005).

Zygapophyseal joints are a common source of spinal pain. In a series of 500 participants with chronic spinal pain and using ZPJ injections as a diagnostic tool, the prevalence of ZPJ pain in the cervical spine was determined to be 28%, thoracic spine 6% and lumbar spine 25% (Manchikanti et al., 2004). Provocation procedures and diagnostic blocks have also confirmed lumbar ZPJs are a source of pain in healthy volunteers (Mooney, Cairns, & Robertson, 1976) and those with chronic lumbar pain (Marks, 1989; Schwarzer et al., 1994; Schwarzer, Wang, Bogduk, et al., 1995). One of the earliest cervical ZPJs trials involved 24 participants with undiagnosed cervical pain. Using diagnostic 0.5% bupivacaine blocks into cervical ZPJs, complete relief of symptoms was achieved for at least 2 hours in 17 participants (Bogduk & Marsland, 1988). In a subsequent study, one of the authors performed ZPJ blocks on 128 participants with chronic neck pain, obtaining short-term relief in 82 of the participants (Aprill & Bogduk, 1992). Longer term symptom relief of ZPJ pain, has been achieved using percutaneous radiofrequency neurotomy of the dorsal rami branches and denaturing the nerves suppling the ZPJs (Lord, Barnsley, Wallis, McDonald, & Bogduk, 1996).

While ZPJ injections have assisted in identifying the ZPJ as a source of pain and in situations of ZPJ degeneration subchondral bone is capable of producing pain, there are no radiographical features on computed tomography that correlate with the painful ZPJ (Schwarzer, Wang, O'Driscoll, et al., 1995). Given the role ZPJs have in limiting spinal movement, it seems plausible there is a mechanical pathway by which spinal load could provoke ZPJs. It is plausible that ZPJs articular cartilage could be a source of night and waking spinal symptoms, if degenerative and subjected to sustained sleeping postures involving torsion or extension. Most likely in healthy joints with no degenerative changes, the source of pain is the ZPJ capsule, rather than the articular processes and associated articular hyaline cartilage. The ZPJ capsule as a potential source of symptoms will be discussed in Section 2.4.2.4.

2.4.2.3 Uncovertebral Joints

Unique to the cervical spine, are the uncovertebral (Luschka) joints, found in the lateral portion of cervical vertebra three to seven. These are formed by a raised lip of the distal vertebral body (uncinate process), meeting a similarly curved surface from the superior vertebral body (Taylor, 2018). As the uncinate develops from late childhood, corresponding horizontal fissures develop in the posterior IVD. The fissures start from the uncinate process and spreading medially, so that by their early 30's young adults usually do not have an intact nucleus surrounded by the annulus, as is the norm in other portions of the spine (Taylor, 2018). The uncovertebral joints allow flexion and extension but limit side bending.

2.4.2.4 Spinal and Capsular Ligaments

Ligaments are important restraints to spinal movement. Spinal and capsular ligaments are highly innervated viscoelastic tissues that are subject to creep. In animal studies, it has been demonstrated there is a much higher density of high threshold mechanosensitive units in the capsular ligaments than the surrounding muscles (Yamashita, Cavanaugh, El-Bohy, Getchell, & King, 1990) and human cadaveric studies have demonstrated the presence of pro-inflammatory chemicals in the capsular ligaments of the cervical spine, suggesting they may be directly involved in pain generation (Kallakuri, Singh, Chen, & Cavanaugh, 2004).

There is a greater range of motion available in the cervical than the lumbar spine. This increased range of cervical motion is significantly greater in females up to 50 years of age. The range of cervical motion decreases in both genders with age, except at the atlantoaxial joint (Dvorak et al., 1992). Without a posterior anulus in the cervical spine and because of ZPJ orientation, true rotation is limited by elongation of the capsular ligaments and anterior anulus fibrosus (Bogduk & Mercer, 2000). This is in comparison to the lumbar spine, where with compression the ZPJ or without compression, the anulus fibrosis primarily limit rotation. In the lumbar spine, ligamentous restraint to forward bending is primarily provided by the posterior longitudinal ligament and at end range the ligamentum flavum. Backward movements are resisted by the anterior longitudinal ligament (Hukins et al., 1990). In the cervical spine, flexion is primarily limited by ligamentous tissues, in this case by the posterior ligaments, posterior longitudinal, capsular, ligamentum flavum, and interspinous (Bogduk & Mercer, 2000). Sectioning of the posterior ligaments in the cervical spine, doubles the range of available flexion and rotation, indicating the important role these ligaments have in providing passive spinal support (Wen et al., 1993). Spinal ligaments have been shown to develop injuries following flexion (Webb, Broughton, McSweeney, & Park, 1976), extension (Yang & King, 1984) and rotation (Farfan et al., 1970) loads. The greater range of motion and reliance on viscoelastic restraints in the cervical spine, suggests that sustained cervical flexion or rotation loads could result in increased creep and be associated with symptom provocation, more so than in the lumbar spine.

2.4.2.5 Muscle

Muscle contains both active and passive components. The active component is contractile, consisting of actin and myosin elements that generate load through activity. The passive elastic component includes three collagenous sheaths, perimysium, epimysium and endomysium, which undergo creep and hysteresis if subjected to sustained elongation loads. When subjected to elongation load, muscles have a greater capacity than other viscoelastic tissues to lengthen before injury. Most nociceptors are found within collagenous sheaths and surrounding a muscle (Adams et al., 2006).

Muscle contraction is known to generate most of the compressive load acting on the lumbar spine (Kingma et al., 2001), which provides stability and reduces lumbar spinal load (Rohlmann et al., 2012). While muscle contraction also provides compressive support in the cervical spine, due to differences in morphology muscle contraction results in a much greater range of movement than in the lumbar spine. As a result, there is a larger neutral zone in the cervical spine, where it is inherently unstable in the middle ranges of movement (Moroney, Schultz, Miller, & Andersson, 1988; Wen et al., 1993). Muscle contraction provides an important contribution to spinal stability but can only occur when a person is awake. During the sleep cycle, muscle contraction diminishes during transition from Stage 1 to Stage 2 and during REM stages muscle function is at its lowest (Hobson, 2005). Even in participants with spasmodic torticollis, abnormal muscle activity abolishes after Stage 2 (Lobbezoo, Thon, Remillard, Montplaisir, & Lavigne, 1996). Due to muscle elasticity and generally relaxed state while sleeping, it seems likely that (a) muscle tissue will not be a primary source of pain; and (b), without the protective action of muscle contraction during sleep, the lumbar and cervical spine passive tissues, could be exposed to sustained loads.

However, muscular activity can arise as a powerful reflexive activity, muscle spasm, due to the stimulating effects of nociceptors in nearby tissues. Several authors have shown that neuromuscular hyperexcitability in muscles exists when nearby tissue is damaged (Bove et al., 2003; Cavanaugh, Lu, Chen, & Kallakuri, 2006; Dilley & Bove, 2008b; Solomonow, Zhou, Harris, Lu, & Baratta, 1998; Stubbs et al., 1998). An integrated biomechanical, collagen biology and motor control model has been proposed (Solomonow, 2012). Low flexion loads (20 Nm peak) were applied six times to a feline lumbar spine over a 10 minute period, followed by 10 minutes of rest. The spines were then rested for 7 hours at no load, before the supraspinous ligaments were harvested and analysed for pro-inflammatory cytokines, interleukin 1, 6, 8, and tumor necrosis factor alpha. The harvested ligaments demonstrated a significantly elevated expression of pro-inflammatory cytokines in comparison to control ligaments from the same animals. During the low load testing, irregular and random muscle spasms were observed, which from a neurological perspective, represented injury potentials being triggered by micro ruptures in collagen fibres. It was concluded, that sustained or repeated low load, resulted in muscle hyper excitability, that was secondary to associated viscoelastic tissue damage and subsequent inflammation. It is possible that while muscle is unlikely to be primarily damaged, it may respond to irritant substances in nearby tissues and contract. Sustained and aberrant muscle contraction has been proposed as a source of pain (Shah, 2009; Shah et al., 2008; Shah & Gilliams, 2008).

2.4.2.6 Nerve

Nerve tissue can be injured either by elongation or compression. Rabbit peripheral nerve displays similar viscoelastic properties to other collagen based tissues under elongation strain; toe-phase, creep and linear elongation to failure (Kwan, Wall, Massie, & Garfin, 1992). During in vitro animal studies, intraneural venular blood flow is impaired in rabbits at 8% nerve elongation and complete intraneural ischemia occurs at 15% elongation (Lundborg & Rydevik, 1973). However, in an in vivo situation restraining structures like the anulus fibrosus and spinal ligaments will uncrimp at less than 3% elongation, develop increasing stiffness and provide protection against neural tissue elongation. It is therefore unlikely that 8% nerve elongation would occur while sleeping, unless other factors like intoxication (Kornetzky, Linden, & Berlit, 2001) or benign joint hypermobility syndrome (March, Francis, & Webb, 1988) overrode normal protective nociceptor responses to excessive load. Short term (i.e., less than a few hours) nerve compression in the order of 20 to 30 mm Hg in animal studies, has resulted in the reduction of intraneural blood flow and both fast and slow axoplasmic flow. These changes compromise target cell nutrition, intraneural communication and develop nerve mechanosensitivity secondary to irritation at the site of compression (Dilley & Bove, 2008a; Rempel, Dahlin, & Lundborg, 1999). As a result of nerve trunk irritation and subsequent mechanosensitivity, neural tissues that normally would not produce sustained impulse generation, could produce impulse generation following the application of minor or slowly applied loads (Howe, Loeser, & Calvin, 1977).

Clinical studies have reported waking neuropathies in the fibular (Lomaglio & Canale, 2017; Toğrol et al., 2000), radial (Lotem et al., 1971; Spinner, Poliakoff, & Tiel, 2002), sciatic (Kornetzky et al., 2001; March et al., 1988), and median (March et al., 1988) nerves, that were not present on retiring. These findings indicate that sleeping postures could contribute to waking symptoms of pain, paraesthesia and nerve dysfunction. Sleep duration between posture shifts is on average 15 to 20 minutes (De Koninck et al., 1983; Johnson, Swan, & Wiegand, 1930) and applied loads during the night are minimal under normal sleeping circumstances. For these reasons, it is unlikely that nerve elongation or compression sufficient to cause symptoms in people not intoxicated and with healthy neural tissue, would occur. However, neural mechanosensitivity and pain generation secondary to the release of pro-inflammatory chemicals from damaged nearby collagenous tissues is potentially possible.

2.4.3 Summary of Section 2.4 Spine Symptoms

To experience symptoms, spinal tissues would need to be both innervated and subjected to loads that exceeds the tolerance of the tissue. When asleep, the unloaded spine relies predominantly on innervated and viscoelastic tissues like ligaments, ZPJ capsules and the anulus fibrosus for protection against elongation loads. Clinical studies have shown that sustained or repeated low loads have demonstrated creep in association with pain and muscle spasm in healthy volunteers and the presence in animal studies, of pro-inflammatory substances in ligaments subjected to repeated low loads. Further, lumbar IVD nutrition and cellular repair is probably compromised by sleep postures that cause sustained lumbar extension.

Classification and measurement of sleep posture, specific sleep postures and spinal symptoms, factors influencing sleep posture and the ability to change sleep posture are discussed next.

2.5 Sleep Posture

There is no single definition of posture in the ergonomic literature. It has been defined (a) anatomically, as the configuration of head, trunk and limbs in space; (b) biomechanically, as a semi static biomechanical alignment (Rohmert & Mainzer, 1986); or (c) functionally, as postures adopted to suit the task being performed (Corlett, 1981). Posture is influenced by many factors including the task at hand, the environment and anthropometric dimensions of the individual. In this section, the development, stability and classification of sleep posture will be reviewed, followed by methods used to measure sleep posture and associations between sleep posture and spinal symptoms. Factors influencing sleep posture and changing sleep posture will be examined in the final two sections.

2.5.1 Development and Stability of Sleep Posture

Children first develop preferred sleep postures at around 3 months of age when they are able to move freely in bed, and by age seven, they have developed definitive sleep posture routines (Dunkell, 1977). These sleep posture routines vary from person to person, more so than variation within an individual's sleep routine from night to night (Chen et al., 2013b; Deun et al., 2012; Kubota et al., 2003; Verhaert et al., 2009, August).

Children (3 to 12 years of age) change posture 40 or more times a night (De Koninck et al., 1992) while adults change posture approximately half this frequency per night (Bader & Engdal, 2000; Chen et al., 2013b). However, this varies significantly ($p < .05$) between poor and good sleepers, with poor sleepers changing posture on average 35.6 times per night, while good sleepers change posture 22.3 times per night (De Koninck et al., 1983). With increasing age, the number of posture shifts per night decreases (Lorrain & De Koninck, 1998) and long periods of postural immobility (LPPI), which are postures sustained for greater than 30 minutes increases (De Koninck et al., 1992). Posture shifts also vary according to mattress firmness, with a greater number of shifts occurring on firmer mattresses (Suckling, Koenig, Hoffman, & Brooks, 1957).

Ontogenetic research indicates that children free to move in bed spend an equal portion of the night in supine, side lying and prone (De Koninck et al., 1992). If children are unable to move freely, they are at risk of developing distorted body shapes and supported, symmetrical postural care is recommended (Goldsmith, Goldsmith, & Goldsmith, 2000). European adults spend most time in side lying, followed by supine and the least amount of time in prone (De Koninck et al., 1992; Gordon et al., 2007a) while Chinese adults spend the greatest amount of time in supine (Chen et al., 2013b). With increasing age, European adults spend less time in prone and a greater amount of time in side lying (De Koninck et al., 1992; Gordon et al., 2007a).

It is plausible that with increasing age, the general trend of fewer posture shifts occurs because provocative sleep posture like prone are avoided and more time is spent in supportive postures. Conversely, adults who continue to sleep in postures provocative of spinal tissues, may experience more posture changes and less LPPI due to tissue discomfort.

2.5.2 Sleep Posture Classification

Most commonly sleep posture is classified into supine, side lying and prone (Abanobi, Ayeni, Ezeugwu, & Ayeni, 2015; De Koninck et al., 1983; De Koninck et al., 1992; Deun et al., 2012; Gordon, Grimmer, & Trott, 2004; Gordon et al., 2007a; Lorrain & De Koninck, 1998). In this three-level classification, supine is when the chest faces the roof, prone is when the chest faces the floor and all other postures are considered side lying. Some researchers include classifications like 'mixed' (Desouzart, Vilar, et al., 2014), 'varies' (Gordon et al., 2007a) or 'unsteady' (Abanobi et al., 2015) to indicate a mixed sleep posture or a transition (Desouzart, Filgueiras, et al., 2014) from one sleep posture to another. Classifications of 'upright' and 'sitting' have also been used in some studies (Desouzart, Filgueiras, et al., 2014; Gordon et al., 2007a). Rather than identifying key sleep postures, some researchers classify sleep posture based on body part domains. One group of researchers classified sleep posture into four domains based on head, trunk, legs and arm positioning resulting in 28 sleep postures (De Koninck et al., 1983), while another group of researchers used three domains based upon head, chest and waist orientation, also resulting in 28 sleep postures (Kubota et al., 2003). These methods allow for classification of larger numbers of sleep postures, but they have not been adopted by other researchers.

With approximately 60 to 70% of sleep time spent in side lying (De Koninck et al., 1992; Gordon et al., 2007a), it is appropriate to consider if this is a homogenous posture. Prior authors have noted intermediate side lying sleep postures and classified them based upon pelvic orientation (Verhaert, 2011) or arm and leg positions (Hsia et al., 2009). Classification of side lying could also be based upon putative spinal load. In this way, postures that increase spinal loading (e.g., end range rotation or extension) are considered potentially provocative, and those that minimise spinal loading, are relatively supportive. It is known that a percentage of people wake with spinal symptoms not present going to sleep or do not experience alleviation of retiring symptoms (Excoffon & Wallace, 2006; Goldman, 2005; Gordon et al., 2010; Gordon et al., 2002; Miller, 1984) and that sleep postures, including intermediate postures have been implicated (Verhaert, Haex, De Wilde, Berckmans, Vandekerckhove, et al., 2011). In this section, sleep postures including intermediate postures, will be examined with respect to their potential for provocation or support of spinal tissues (Figure 14).

2.5.2.1 Supine

Supine is generally defined as chest facing the ceiling, with or without trunk rotation (Cary, Collinson, Sterling, & Briffa, 2016; Desouzart et al., 2016; Gordon et al., 2007a). Considered biomechanically neutral, supine is generally not associated with spinal symptoms, but has been associated with restless sleep, snoring and sleep apnoea (Cartwright, 1984; De Koninck et al., 1992). With the addition of a pillow under the knees to minimise lumbar lordosis, supine is generally a comfortable posture for people with spinal stenosis or lumbar pain (Boissonnault & Di Fabio, 1996; Desouzart et al., 2016). Different to European norms, it has been reported that Chinese and Japanese people spend the majority of time asleep in supine (Chen et al., 2013b; Fukuda, Ogilvie, Chilcott, Vendittelli, & Takeuchi, 1998).

2.5.2.2 Side Lying and Intermediate Postures

Most studies report side lying as the posture that people spend greater than 60% of the night (De Koninck et al., 1992; Gordon et al., 2004; Haex, 2005; Johnson et al., 1930). In an observational study involving 812 phone interviews, it was found side lying provided the most protection from waking cervical symptoms (Gordon et al., 2002). De Koninck et al. (1983) found side lying postures with both arms and legs folded greater than 45^0 were sustained the longest, indicating this to be a stable and comfortable posture. However, due to the elevated centre of gravity and decreased surface contact area, side lying is inherently unstable (Haex, 2005). As a result, there are a large variety of side lying postures, some symmetrical and others not, with possible implications for varied spinal loads. Some researchers have divided side lying into different subcategories (Hsia et al., 2009) and others acknowledge a link between intermediate side lying postures and spinal torsion (Verhaert et al., 2012). It is plausible, that symmetrical and supportive side lying postures would provide greater spinal protection and subsequently less tissue load. To examine this possibility, side lying was sub classified into supported side lying (SSL) and provocative side lying (PSL), based upon spinal symmetry.

2.5.2.2.1 Supportive Side Lying

Supportive side lying was defined as the top thigh resting on the lower thigh, knee or tibia (Figure 14). Both legs could be straight, but with a high centre of gravity, people usually bend their hips and knees to greater than 45^0, thereby increasing trunk stability. This posture minimises pelvic and spinal torsion in the transverse plane, due to symmetry and placement of the lower limb. A pillow is sometimes used to cushion the bony femoral condyles of the medial knees and has been recommended to assist spinal support (Desouzart, Filgueiras, & Matos, 2015).

Figure 14. Sleep posture classification. The majority of sleeping European adults sleep in side lying. To examine the possible effects of sleep posture on spinal symptoms, side lying was sub classified into two intermediate postures based upon spinal loading; supportive and provocative side lying.

2.5.2.2.2 Provocative Side Lying

Provocative side lying occurs with additional flexion of the top thigh from a SSL posture and subsequent loss of contact with the lower thigh (Figure 14). The top knee will lower to the mattress, inducing hip adduction and lumbar rotation. Coupled rotation will occur in the same direction as discussed in Section 2.3.1.5. At the same time, the lower hip and thigh are blocked against the bed, resulting in lumbar lordosis and spinal extension (Verhaert, Haex, De Wilde, Berckmans, Vandekerckhove, et al., 2011). If the lower shoulder is retracted, trunk rotation increases and progresses up the thoracic spine and into the cervical spine.

2.5.2.3 Prone

Prone is commonly defined as the chest facing the floor and both knees straight and is the sleep posture used least by adults (Cary et al., 2016; De Koninck et al., 1992; Gordon et al., 2007a). In prone, lumbar and cervical spine extension is increased and to facilitate breathing, the cervical spine is positioned in near full rotation. Extension reduces both central and lateral canal diameters of the lumbar and cervical spine (Harrison, Cailliet, Harrison, Troyanovich, & Harrison, 1999), potentially compressing spinal cord and peripheral nerve tissue (Goldman, 2005; Holman, 2008). In prone, the lumbar disc thickens posteriorly, increasing the distance of diffusion and reducing the optimal flow of nutrients into the IVD as noted in Section 2.4.2.1.2.

Prone has been noted to aggravate 49% of participants with existing lumbar pain (Boissonnault & Di Fabio, 1996) and avoiding prone is commonly recommended (Bland, 1987; Grieve, 1988; Kraemer, 2011). With increasing age, prone is adopted less frequently (De Koninck et al., 1992; Gordon et al., 2007a) which may represent a learned protective response or reaction to increased tissue stiffness.

2.5.3 Measurement of Sleep Posture

A recent systematic review identified the need for a non-invasive, low cost and user friendly objective measurements of sleep, that can be deployed into non-laboratory environments (van De Water et al., 2011). Self-reported sleep posture, other than supine was found to be unreliable in a pilot study examining sleep posture in a home environment, when compared with data recorded using dual infra-red (IR) cameras (Cary, Collinson, Sterling, & Briffa, 2014). See Appendix 23. Further, we conducted a scoping review and identified the need to use an objective measure of sleep posture and not rely solely on self-reported sleep posture (Cary, Briffa, et al., 2019). Current sleep posture assessment can broadly be divided into two categories, non-technological and technological.

2.5.3.1 Non-Technological

Self-report is the most common form of non-technological measure of sleep posture, however self-report by its nature is uncertain, as it refers to a period of time when participants are not fully conscious. Self-report has been collected using oral (Abanobi et al., 2015; Gordon et al., 2007b) and written questionnaires

(Boissonnault & Di Fabio, 1996; Noll et al., 2017), however these have not been validated against a known standard of measuring sleep posture. For example, when examining participants with non-specific cLBP prior to the provision of a new mattress, researchers used self-report to classify participants' sleep posture into "supine knees bent", "supine knees straight", "fetal", "three quarters", "prone" and "other", but self-report was not validated (Kovacs et al., 2003, p. 1601). In a group of healthy participants (*N* = 12), videography from two nights was obtained using a single IR camera in a sleep laboratory (Gordon et al., 2004). Data collected were used to compare participants' self-reported dominant sleep posture during a normal night's sleep. To test self-reported reliability, results from night 1 and night 2 were compared and to test validity of self-report, time spent in each sleep posture was compared with the participant's self-reported dominant sleep posture. Neither intra-rater reliability of the scorer nor validity of the sleep posture classifications was reported.

The accuracy of self-report may vary from person to person and be influenced by the stability of their sleep routine. When exploring the relationship between sleep posture (supine, side lying and prone) and primary open angle glaucoma (*N* = 29), self-report was compared to continuous posture monitoring using an Embletta X10 sleep monitor and the recorded sleep posture only matched the primary self-reported sleep posture in 77% of participants (Kaplowitz et al., 2015). In another study, an IR camera was used to record the sleep posture of 300 participants, while exploring the relationship between sleep posture and OSA. Self-report was found to be inaccurate and the authors concluded "that objective position monitoring can be an important complement to self-report" (Russo & Bianchi, 2016, p. 127). The variation in reliability of self-report, may be explained by a more recent study in which participants were recorded over two nights in a sleep laboratory (Yu, 2018). Self-report was compared with video recordings that were coded by two independent assessors. When asked to identify their dominant sleep posture, inaccuracy between self-report and actual was nearly 33%. It was noted, that healthy participants who spent longer periods of sleep in one posture, especially if their hands were placed on their stomach or chest, were more accurate in identifying their dominant sleep posture. It was concluded by the authors that while self-report is inexpensive, researchers should be cautious in using it as an objective measure due to the dynamic nature of sleep and especially if participants do not have a dominant sleep posture.

It is also important to note what is actually being self-reported. Some researchers ask participants to self-report the posture they are in when they go to sleep and when they wake (Cary et al., 2016; Gordon et al., 2007a; Marin, Cyhan, & Miklos, 2006) and others ask participants what posture they think they are in for most of the night (Abanobi et al., 2015; Gordon et al., 2004; Josefson, 2001; Kim, Jeoung, Park, Kim, & Ritch, 2014). Self-reported answers to these questions do not fully encompass the variety or accurately determine the duration of time spent in each sleep posture.

2.5.3.2 Technological

The bulk of sleep research is currently undertaken in sleep laboratories using polysomnography (PSG), which is considered the gold standard when assessing sleep parameters related to sleep pathologies like OSA, insomnia and restless legs syndrome. Access to utilise sleep laboratories for sleep posture research is limited due to high demand from priority patient groups, metropolitan only locations and associated high financial costs. Further, participants in these situations have multiple sensory attachments (Eastwood, 2009 personal communication), which combined with the unfamiliar environment, create an abnormal vigilance sleep phenomenon called the first night effect (Kronholm, Alanen, & Hyyppä, 1987; Tamaki & Sasaki, 2016). To minimise the first night effect, one or two adaption nights of recording are usually undertaken but discarded before analysis (Gordon et al., 2004). For these reasons, while the following technological methods have been used to assess sleep posture, generalisability of results to non-pathological patient groups and access to laboratory environments is limited.

2.5.3.2.1 Visual

Early assessment of sleep posture involved direct visual observation and line drawings. The first automated data collection was in 1930, when a 16 mm camera was used to film participants during their sleep (Johnson et al., 1930). The method of this study involved illumination with a 100W globe, the brightness of which may have influenced sleep postures adopted. These early researchers observed that each subject had their own repertoire of sleep postures, repeating them consistently from one night to another. With film improvements, visual observation progressed to using a Nizo Super 8 camera and a 7W globe, which was less visually intrusive (De Koninck et al., 1983). Researchers now use IR illuminated videography, commonly from one camera, as part of a full PSG assessment (Drakatos, Higgins, Kosky, Muza, & Williams, 2013). This method has been used to determine sleep posture (Desouzart et al., 2015; Desouzart, Vilar, et al., 2014; Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011) or as the gold standard to compare the measurement of sleep posture using other equipment (Kuo, Yang, Tsai, & Lee, 2004; Liao & Yang, 2008). Image capture from one camera potentially limits the accuracy of posture recognition due to bed covers reflecting light and a limited depth of field. For this reason it has been recommended that image capture occur in two visual planes, to improve the accuracy of video data interpretation (Rebelo, Filgueiras, & Soares, 2011). Infrared illumination eliminates the need for white light, which is known to interfere with sleeping, but using IR light in total darkness, creates non-uniformities in contrast, most commonly with overexposure at the centre of recorded images (Liao & Yang, 2008). Concerns in association with IR videography have previously been reported in regard to privacy and also image quality and data storage (Liao & Yang, 2008). However, with modern equipment, image quality and data storage are now of minimal concern.

2.5.3.2.2 Sensor Assessments

Other forms of technological assessment include pressure mattress indentation (Abraham, Sullivan, & Ranganathan, 2011; Harada, Sato, & Mori, 2001; Hsia et al., 2009; Pino, Dorner De la Paz, Aqueveque, Chavez, & Moran, 2013; Stinson, Porter-Armstrong, & Eakin, 2003; Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011), static charged beds (Tamura, Miyasako, Ogawa, Togawa, & Fujimoto, 1999), thermal imaging (Lu, Tamura, & Togawa, 1999), and body markers with 3D scanning (Drerup & Hierholzer, 1987). Actigraphy is a commonly used in sleep research because of the associated low cost and ability to automatically collect data from several days to weeks (Lichstein et al., 2006). Actigraphy commonly involves the wearing of a small accelerometer and in this way only measures the movement of the limb wearing the accelerometer (Verhaert, 2011). More recently, three triaxial accelerometers were placed on participants' mid-thigh, upper back and dominant upper arm, to assess sleep posture and posture movements. The accelerometer placed on the upper trunk enabled the classification of sleep posture into front, back and side and a posture needed to be maintained for a least 1 minute (Skarpsno, Mork, Nilsen, & Holtermann, 2017). No validation of these sleep postures was undertaken in this study. It is also possible that wearing three, on body sensors could alter the normal sleep postures and sleep routines of participants.

For a long time, assessment of sleep posture has been of minor importance in the realm of sleep disorders and evaluated by self-report or a single camera. More recently, with the recognition that sleep posture has a contributing role in OSA and with an increased interest in researching sleep systems, greater emphasis has been placed on accurately determining sleep posture. As a result, numerous technological methods have been developed, but are predominately used in sleep research laboratories. What is still required is a cost effective, portable, and validated measure to assess sleep posture in the home environment.

2.5.4 Sleep Posture and Spinal Symptoms

Sleep is considered essential for human mental and physical recovery. Yet, every night some people go to bed, only to wake with spinal symptoms not present the prior evening, while others with existing spinal symptoms, wake with exacerbations of their symptoms (Desouzart, Filgueiras, et al., 2014; Desouzart, Vilar, et al., 2014; Gordon et al., 2007a; Yim, 2015).

In comparison to sitting and standing, lying down has the greatest unloading effect on the spine (Waddell, 2004). It has been noted that prolonged or asymmetrical postures can have a cumulative effect, with resultant loads exceeding tissue thresholds and resulting in symptoms. See Section 2.3.2.3.4. These applied loads need not be sudden in onset to cause symptoms and may account for dysfunctions later in life (Gorski, 2018; Kumar, 2001; Norman et al., 1998). It has been postulated that some sleep postures may be responsible for the production of both night-time and waking cervical and lumbar symptoms (Cary et al., 2016; Corrigan & March, 1984; Gordon et al., 2002; Gracovetsky, 1987; McKenzie & May, 2006).

The concept of spinal symptoms as a result of sleeping postures has been explored in several studies. When examining cervical symptoms of pain, stiffness, headache and scapular pain via a phone questionnaire, it was found that 46% of participants experienced waking symptoms at least once in their usual week (Gordon et al., 2002). Of the participants experiencing waking symptoms, 44% reported them as lasting an hour or less. The authors proposed a postural hypothesis to explain the waking cervical symptoms, noting that more persistent day symptoms would most likely be due to an underlying disorder, while intermittent symptoms as noted to be more likely the result of a nocturnal postural stress (Gordon et al., 2002). Using the same data set, researchers examined self-reported sleep posture, neck symptoms and sleep quality. They found side lying provided protection against waking cervical symptoms and that side lying was rated by participants as providing the highest quality of sleep (Gordon et al., 2007a). The concept of nocturnal postural stress, resulting in waking symptoms that dissipate on movement has been noted by others. An earlier study examined male participants working in physically light (N = 471) and heavy (N = 666) occupations, and found that 45.3% and 43.0% respectively woke with neck pain or stiffness (Hult, 1954). These symptoms were attributed by the participants, to an uncomfortable sleeping posture and were reported to commonly disappear within a few hours of waking. In another study, 41% of participants with cLBP who completed a comprehensive pain questionnaire, noted they experienced their worst pain in the morning. Fifty-three percent reported they experienced night-time pain severe enough to wake them, of which 77% stated they were able to fall back asleep following a change in sleep posture. When lying down, 49% of participants reported prone increased their symptoms, while over 80% reported side lying as preferable for pain relief (Boissonnault & Di Fabio, 1996).

To the author's knowledge, only one intervention study has specifically measured spinal symptoms following a change in sleep posture (Desouzart et al., 2016). In this study, older and physically active female participants (N = 20), were recruited and randomly divided into control and intervention groups. The method of randomisation was not reported. Participants in the intervention group were instructed to sleep in side lying or supine with pillow support and to avoid prone. After a 4 week intervention period, pain VAS measures were repeated. There was a statistically significant reduction in pain in the intervention group (p = .009), but not the control group. Study outcomes are limited because between group differences were not reported and were likely to have been non-significant. See Section 6.4.6. Also, the limited age and gender range limits generalisability and sleep posture was not objectively confirmed at baseline or after the intervention period. Another intervention study included postural education as an intervention, however the outcome measures were for sleep quality and not symptoms (Desouzart et al., 2015).

Common to all studies in this section, was the identification of a plausible association between sleep posture and spinal symptoms. However, the limited number of studies, gender and age groups and lack of use of a validated measure of sleep posture, restricts any firm conclusions.

2.5.4.1 Supine

While sleeping supine is strongly associated with positional sleep apnea, the relationship with spinal symptoms is not so clear. Self-reported supine sleep posture was found to be provocative of pain in the lumbar spine (OR = 1.92, (95% CI: 0.43, 8.56), p = .31) (Abanobi et al., 2015) and the cervical spine (OR = 1.40, (95% CI: 0.8, 2.50)) (Gordon et al., 2007a), but was not statistically significant in either study. However, only considering trunk position may not tell the full story. The majority of participants in a study with cLBP, found lying in supine with their legs extended to be highly provocative, but when in supine with their hips and knees flexed their lumbar pain was alleviated (Boissonnault & Di Fabio, 1996).

2.5.4.2 Side Lying

Side lying is the posture in which the majority of people spend most of the night, regardless of being healthy (De Koninck et al., 1992; Haex, 2005) or experiencing pain (Boissonnault & Di Fabio, 1996; Marin et al., 2006). Right side lying is generally more common than left side lying (De Koninck et al., 1992; Kaplowitz et al., 2015) possibly to reduce compression on the heart or to facilitate gastric function. Side lying is considered the ideal sleeping posture for spinal recovery; one that reduces stress, relaxes muscles, promotes symmetrical body balance, maintains normal spine curves, improves metabolite exchange and equalises stress between intervertebral disc and the neural arch (Adams et al., 2006; Dolan, Adams, & Hutton, 1988; Gracovetsky, 1987; LeBlanc, Evans, Schneider, Wendt III, & Hedrick, 1994; Nachemson & Elfstrom, 1970). De Koninck et al. (1992) found side lying postures with both arms and legs folded 45 degrees or greater, were sustained for the longest periods of time across all age groups in healthy individuals, indicating the posture was comfortable. Side lying was found to be significantly protective against cervical pain (OR = 0.6, (95% CI: 0.4, 0.9)) (Gordon et al., 2007a), and was one of two recommended sleep postures for those with lumbar pain (Desouzart et al., 2016).

However, in possibly the first treatise examining sleep posture and spinal pain, the importance of avoiding side lying with trunk rotation was emphasised. The author believed this posture resulted in passive trauma to the costovertebral and intervertebral ligaments (McDonnell, 1945). A non-symmetrical side lying posture, will promote spinal rotation and extension, potentially increasing spinal loads on viscoelastic tissues. For this reason, as discussed in Section 2.5.2.2, it makes biomechanical sense to sub-classify the dominant sleep posture of side lying into supportive and provocative side lying postures, based upon plausible tissue loading and possible symptom provocation.

2.5.4.3 Prone

There is an abundance of anecdotal recommendations to avoid the prone sleeping posture because of an associated increase in spinal symptoms (Bland, 1987; McDonnell, 1945; McKenzie & May, 2006). In a series of case reports, detailing self-reported prone sleepers aged 13 to 64 years (N = 23), with cervical and lumbar pain, sleepers were recommended to adopt a normal sleeping posture (Miller, 1984). No details were provided on how the participants' sleep posture was confirmed beyond self-report, nor what was a normal sleeping posture. The author reported providing education as a first line of treatment, recommending the adoption of a normal sleeping position. The author noted it could take months to establish a new sleeping pattern and advised concomitant manual therapy to commence after 1 month if necessary. The author followed this group for several years and noted that 74% reported satisfactory improvements over 6 months and experienced a 39% reoccurrence rate over 3 years.

Extension is known to reduce central and lateral spinal canal diameter and therefore potentially compromise neural structures. Nocturnal exacerbation of neuropathic symptoms that disrupt sleep can occur in people with spinal stenosis, with or without peripheral neuropathy (Goldman, 2005). In one retrospective study, participants with diabetic peripheral neuropathy were advised to use a walking frame during the day to encourage lumbar flexion and to sleep in supine (pillow under knees) or side lying (pillow between knees) or prone (pillow under stomach), in an attempt to limit lumbar extension. Improvement of symptoms in eight of 11 participants was reported, commonly with significant symptom reduction within 24 hours (Goldman, 2005). How compliance with postural recommendations was monitored, was not reported. However, the speed with which nocturnal symptom control was improved in a chronic condition is noteworthy. It implicates a biomechanical component in the nocturnal symptom provocation, that when postural loads are altered is reversible.

Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al. (2011) measured self-reported sleep quality from 17 healthy participants, when comparing a sagging and a personalised supportive sleeping system (i.e., mattress and base). Cluster analysis identified two separate subgroups based upon their preferred sleep postures. The first cluster spent proportionally more time in side lying and prone and reported significantly poorer quality of sleep on a sagging sleep system, than on the personalised sleeping system. The second cluster, spent proportionally more time in side lying and supine and had no difference in sleep quality on the sagging or the personalised sleep systems. This study suggests that when healthy participants experience poorer quality of sleep, it may in part be related to sleep posture. It is biomechanically plausible, that a sagging sleep system will accentuate the extent of lumbar extension in participants that prefer to sleep in PSL and prone, by placing spinal tissues under increased load as discussed in Section 2.5.2.3.

Using a single IR camera to record the sleeping postures of young female university students (N = 12), it was noted the students spent 28.7% of their sleep time in prone (Desouzart, Filgueiras, et al., 2014). This percentage of prone sleeping is much higher than reported by other authors in a similar group of 10 healthy (i.e., no medication, no sleeping disorder) participants (five female, 18 to 24 years of age), who only spent 13.4% of the night in prone (De Koninck et al., 1992). Fifty percent of the university students reported their pain was strongest at night and 25% noted their nocturnal spinal pain was strong enough to disrupt their sleep. In both studies a camera was used to record sleep posture and the differences of time spent in prone may lie in the respective definitions of prone sleeping as discussed later in Section 7.3.1. The association between provocative postures and spinal symptoms is one that warrant further investigation.

2.5.4.4 Sustained Posture

Sleep involves both sustained and repeated postures. Viscoelastic tissues are vulnerable to sustained or repeated low elongation loads and undergo predictable mechanical and viscoelastic changes, like creep, hysteresis and fatigue failure, as discussed in Section 2.3.2.3. Sustained sleep posture habits have previously been investigated with results suggesting that on average, adults changed their posture between 2.1 and 3.6 times per hour (De Koninck et al., 1992). This indicates that sleep postures are commonly sustained for periods of greater than 15 minutes, a time frame in which in vitro viscoelastic collagenous tissue creep has been demonstrated (Yahia et al., 1991) and as a result, unable to return to original length (Solomonow, Zhou, et al., 2003). Associations between biomechanical creep and spinal symptoms in relation to sustained and repeated low loading into flexion has been explored using in vivo asymptomatic human and in vivo feline groups and discussed in Section 2.3.2.3.4. Under sustained rotation for 10 minutes in sitting, a significant increase in trunk axial rotation ($M = 10.5^0$, $SD = 4.2^0$, $p < .001$) occurred in asymptomatic males (Shan et al., 2013). In addition to creep, the authors reported that participants experienced a significant increase in lumbar pain measured using a VAS (M = 48.4 mm, SD = 28.2 mm, $p < .001$).

In more extreme circumstances such as those induced by alcohol, fatigue and certain medications, neural pathologies have been associated with sustained postures, including during sleep (Kornetzky et al., 2001; Miller, 1984; Toğrol et al., 2000). In one reported case in which 1L of vodka was consumed, a student fell asleep in the lotus posture. On waking 6 hours later, he was unable to walk and after nerve conduction studies was diagnosed with acute, non-traumatic bilateral sciatic nerve palsy, due to probable posture induced compression of the sciatic nerves (Kornetzky et al., 2001). In the upper limb, a similar acute non-traumatic radial nerve compression has been reported as a result of non-physiological sleep, with the arm resting on a chair back (Arnold, Krishna, Freimer, Kissel, & Elsheikh, 2012; Barnett & Church, 2018).

In summary, physiological sleep routines entail periods of sustained posture long enough for creep of viscoelastic tissue to occur, if sleep postures are not supportive. It has been demonstrated both in in vivo human and animal studies, that physiological creep has been associated with spinal pain symptoms and augmented muscle activity. Neuropathies have been reported in association with non-physiological sleep and seem to entail compressive rather than elongation loads.

2.5.5 Other Factors Influencing Sleep Posture

Humans spend approximately one third of their life asleep. The importance of sleep enabling our bodies to recover and process the physical and mental loads of the day are well known. What is less well known, are the factors that influence the adoption and maintenance of certain sleep postures. As discussed in Section 2.5.1., healthy adults change their posture 12 to 20 times per night and this increases significantly with poor sleepers. Sleep posture routines vary from person to person and no ideal posture can be maintained all night, as tissue stiffness and pain (Haex, 2005), microcirculation (Vanderwee, Grypdonck, & Defloor, 2008) and possibly the respiratory system (Chapell, 1993), would be adversely affected. Factors that influence which sleep postures are adopted are examined in the next section.

2.5.5.1 Medical Conditions

It has been reported that nearly 60% of participants sleeping upright, do so because of a medical condition (Gordon et al., 2007a). Moreover, participants that slept upright were significantly more likely to report poorer sleep quality (OR = 0.3, (95% CI: 0.1, 0.6)), cervical pain (OR = 2.5, (95% CI: 1.1, 5.5)) and cervical stiffness (OR = 2.6 (95% CI: 1.1, 5.8)). One such medical condition that might cause someone to sleep upright is severe peptic oesophagitis because sleeping upright is beneficial for the management of gastric fluid irritation (Harvey et al., 1987).

Other medical conditions that have been associated with sleep posture include;

- **Gastroesophageal acid clearance**. Supine and right side lying are associated with increased oesophageal acid reflux and left side lying was encouraged in people with gastroesophageal reflux disease (Khoury, Camacho-Lobato, Katz, Mohiuddin, & Castell, 1999).

- **Glaucoma and floppy eye syndrome.** Relationships between sleeping posture (measured by IR videography) and open angle glaucoma (measured by visual field index) were examined in 29 participants. It was reported that there was a significant decrease in the visual field index of the non-dependent eye in participants that predominately slept in side lying. For example in the left eye of right side lying dominant sleepers (p = .002) (Kaplowitz et al., 2015). However, these results differ from an earlier study in which the authors reported the dependent eye, had a reduced visual field index (Kim et al., 2014). It is possible, this difference was due to the former study using an objective assessment of sleep posture and the latter using self-reported sleep posture. However, these studies demonstrate the adaptive changes that viscoelastic tissues make in response to sustained sleep postures. Exposure to an asymmetric risk factor over a long period of time, such as when sleeping, is enough for side lying to be recognised as a contributing disease mechanism for floppy eye syndrome (Figueira et al., 2014).

- **Musculoskeletal conditions**. Sleep posture has been associated with neck and LBP and stiffness (Desouzart, Filgueiras, et al., 2014; Desouzart, Vilar, et al., 2014; Gordon et al., 2007a; Gordon et al., 2009; Gordon et al., 2002; Gubin et al., 2009), unilateral shoulder pain (Kempf & Kongsted, 2012; Zenian, 2010), increased subacromial pressures (Werner, Ossendorf, Meyer, Blumenthal, & Gerber, 2010), lateral elbow pain (Gorski, 2016, May), hip and groin pain (Grimaldi et al., 2015), bilateral foot drop (Kornetzky et al., 2001), thoracic outlet syndrome (Lee et al., 2011) and carpal tunnel syndrome (March et al., 1988).

- **Nocturnal lumbar pain in late stage pregnancy**. Side lying is recommended to minimise the potential of aortocaval compression syndrome in the later stages (greater than 30 weeks of gestation) of pregnancy. In an early study using PSG to assess sleep posture, the authors compared 13 women in late stage pregnancy; eight with mild nocturnal pain and five without nocturnal pain (Hertz et al., 1992). Researchers found participants in the pain group spent greater periods of time in supine and hypothesised that supine compromised the metabolic supply to neural structures, resulting in pain. In another study involving 52 late stage pregnant participants, it was found they spent 98% of the night in side lying and 2% in supine (Mills, 1994). This group was compared to 31 age matched pre-op gynaecological participants, sleeping in the same environment. These participants spent 58% in side lying, 39% in supine and 3% prone, indicating a high degree of conformity to recommendations. The method, reliability and validity of the sleep posture assessment was not reported.

- **Obstructive sleep apnoea** It has long been recognised that supine sleeping is strongly associated with snoring and sleep apnoea (Kavey, Blitzer, Gidro-Frank, & Korstanje, 1985; Phillips, Okeson, Paesani, & Gilmore, 1986). Polysomnography was used to evaluated sleep posture, in male participants (*N* = 30) with sleep apnoea (Cartwright, 1984). Twenty-four of the participants had an apnoea index twice as high in supine, compared to side lying. The side lying postural advantage decreased in obese participants and the author suggested that participants who are within 25% of their ideal body weight, are likely to be significantly improved in terms of the number of apnoeic events, by sleeping in side lying.

- **Recurrent nephrolithiasis.** Using a sleep questionnaire to ascertain the preferred side lying posture, it was found in a group (*N* = 110) with recurrent nephrolithiasis and who reported sleeping consistently on one side, that 76% developed kidney stones on the dependent side (Josefson, 2001). The authors proposed this was due to sluggish blood flow to the dependent side, allowing crystals to precipitate. The positive predictive value of sleep posture and ipsilateral stone formation was 82% for right side lying and 70% for left side lying.

- **Post-surgery or pressure relief positioning.** Following hip or spinal surgery and in association with acute and painful disease, the avoidance of specific sleep postures has been recommended (Schutz, 1941). Patients are also encouraged to regularly change or receive assistance to change sleep postures to prevent pressure ulcers over bony prominences (Edlich et al., 2004).

- **Spinal stenosis.** The sleep postures of supine or side lying with knee support, were found to be beneficial for symptom control in participants with spinal stenosis and with neurogenic positional pedal neuritis (Goldman, 2003; LaBan, Viola, Femminineo, & Taylor, 1990).

- **Sudden infant death syndrome**. Prone sleeping has been linked to increased vulnerability to sudden infant death syndrome and is not recommended as the position of choice for preterm or term infants (Ariagno et al., 2003)

2.5.5.2 Medications

While no medication directly influences sleep posture, some medications by reducing pain or arousal levels, do influence sleep quality and sleep mobility. Opioids have been used to reduce pain but have a debatable benefit on sleep quality (Shaw, Lavigne, Mayer, & Choinière, 2005) while pregabalin and sodium oxybate appear to improve pain, sleep quality and continuity of sleep. Tricyclic anti-depressants have been found to have mild to moderate positive effects on both pain and sleep quality (Lavigne, Nashed, Manzini, & Carra, 2011). Duloxetine, an anti-depressive medication, has been shown to improve pain in fibromyalgia patients and provide minor improvements in sleep quality (Russell et al., 2008). Sedatives have been shown to reduce the number of posture changes (Barbenel, Ferguson-Pell, & Beale, 1985).

2.5.5.3 Handedness

No clear association has been found between dominant handedness and assumed sleep posture (Boynton & Goodenough, 1930; Stradling & Laird, 1935).

2.5.5.4 Sleep Systems

Non-Base System

Sleeping systems that do not utilise a firm base, like a hammock, limit the adoption of some sleep postures, for example prone, while encouraging others, like supine. However, this type of sleep systems is uncommon in the home environment and won’t be further examined.

Mattress Base System

When designing sleep systems (i.e., mattress, base and pillow), ergonomists aim to optimise support for the human body, facilitating recovery of spinal tissues from the loads associated with diurnal activities. The main design considerations are body contours and weight distribution, both of which are highly individual. Further, body contour contact with the mattress, is also dependent upon the adopted sleep posture, creating an interplay between sleep system and sleep posture (Verhaert, Haex, De Wilde, Berckmans, Vandekerckhove, et al., 2011). As part of a study examining a customised sleep system, researchers identified in 17 healthy participants sleeping over three nights, that the relationship between the sleep posture, as confirmed by PSG and lumbar waking symptoms, was stronger than the relationship between the sleep system and lumbar waking symptoms (Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011).

Other researchers have examined the production of cervical symptoms in relation to sleeping and pillow use. Over a period of seven nights, self-reported side sleeping healthy participants (N = 106), woke with or had maintenance of their retiring symptoms of cervical pain (17.9%) or cervical stiffness (35.8%) (Gordon & Grimmer-Somers, 2010). Sleep posture was not objectively assessed which makes it difficult to draw conclusions about a possible contributing role that sleep posture may have had on waking symptoms. However, other possible contributing factors such as the sleep system (mattress, base and pillow) remained the same throughout the study and any identified unusual events were excluded from the analysis. The authors concluded that the choice of pillow may be only one factor related to a poor night's sleep. Given the exclusion of other factors, it is plausible that their sleep posture may have contributed to provoking their waking symptoms. While examining different spinal regions, both of these studies sought to examine relationships between sleep systems and spinal symptoms, but found possible relationships between sleep postures and spinal symptoms.

2.5.5.5 Sleeping with a Partner

The sleeping routines of 28 married couples were examined in a sleep laboratory over 3 nights. The first night was for adaptation and the other two nights were randomised for either sleeping with or without their partner. When sleeping alone, it was noted there was a significant increase in Stage 4 sleep (F = 37.99, p < .001), and a significant decrease in REM sleep (F = 8.73, p <.01). When sleeping together, there was a significant increase in awakenings (F = 4.38, p < .05). In summary, when sleeping alone, participants experienced more deeper sleep, fewer awakenings and less shallow sleep, however, participants reported less satisfaction when sleeping alone, rather than a decrease in quality of sleep. Sleep posture was not specifically examined (Monroe, 1969). Another study used video recordings to monitor the concordance of movement within a single couple in their home environment over 7 nights. The authors reported that 60% of posture changes initiated by the man and 70% of posture changes initiated by the woman, were matched by their partner (Aaronson, Rashed, Biber, & Hobson, 1980). Sleep postures were not reported.

Pankhurst and Home (1994) conducted two studies using wrist actigraphy. The first study examined the concordance of body movements in couples (N = 46) over 8 nights. The second study examined the effect on concordance of body movements with the presence or absence of a partner and compared participants that normally slept alone (N = 39), with participants who normally slept with a partner, but whom was temporarily absent (N = 56). From the first study, the authors reported that with increasing age there was a significant decrease in the number of posture changes. Using a post hoc Tukey test they reported the real effect lay between the youngest (aged 20 to 34 years) and oldest (aged 50 to 70 years) groups. In the second study, the authors reported a significant decrease in duration of sleep when the partner was temporarily absent (M = 397 minutes, SD = 68 minutes) compared to sleeping with their partner (*M* = 445 minutes, *SD* = 41 minutes). Sleep posture was not reported in either study

Sleep diaries and actigraphy were used to investigate the effect of co-sleeping and sleep location on the quality of sleep in 11 young couples. Like the previous authors, the reported subjective quality of sleep was better for both gender groups when sleeping with their partner ($F = 4.10$, $p = .046$). In young couples, the sleep location did not have an effect on sleep quantity. Sleep posture was not reported (Spiegelhalder et al., 2015).

In summary, it was noted that when partner sleeping, awakenings and number of posture shifts were more frequent, possibly due to changes in posture being triggered by partner movements. Self-reported quality of sleep was better sleeping with a partner, than when sleeping alone. No studies were found that examined specific sleep postures in regard to partner sleeping.

2.5.5.6 Temperature

The ideal room temperature for sleeping is considered to range from 16 to 18^{0}C (60-65^{0}F) (Helmanis, 2006). This allows the body's core temperature and organs to cool and slow their function. The temperature of the skin is modulated by external temperature and internal variations in blood perfusion. Blood flowing in the periphery at approximately 37^{0}C, has been found to be more influential on sleep-wake activity than core temperatures. Mild increases in skin temperature have been reported to promote sleep like brain activity and mild skin cooling temperatures, promote task performance and wakefulness, provided that these temperature changes stay within the normal thermoneutral zone and do not activate thermoregulatory systems to defend larger temperature changes (Romeijn et al., 2012). In fact, field studies trying to improve sleep using a heating blanket actually disrupted sleep, most likely because the blanket added heat to the body and while raising peripheral circulation also challenged the core temperature (Fletcher, Heuvel, & Dawson, 1999). Indirect heating like exercise or hot showers, can increase peripheral circulation and heat dissipation for several hours, without increasing core temperature and have been shown to enhance sleep onset and improve sleep in the first few hours of the night (Raymann, Swaab, & Van Someren, 2007). Thermoregulation is achieved through the evaporation of water, some 0.2L to 0.3L per night, but up to 1L via breathing (33%) and skin evaporation (66%). Greater evaporation needs to occur in environments of higher temperature and as a consequence, there will be an increase in humidity surrounding the body (Haex, 2005). Supine and prone sleep postures maximise contact with the mattress, providing sleep posture stability, but would also reduce air flow, skin evaporation and ability to regulate temperature. Side lying sleep postures are more likely in higher room temperature environments because of the increased exposed surface area, but as a consequence sleep posture stability may be reduced.

In summary, a range of medical conditions influence selected sleeping postures and while medications do not affect sleep posture, some will influence the maintenance and duration of sleep posture. Sleep systems seem to be less important than sleep posture, with regard to maintenance of existing or waking symptoms. When sleeping with a partner, there is a strong concordance of changes in posture, more so in younger couples, with one person's movement initiating movement in the partner. Couples report a better quality of sleep when sleeping together, regardless of location, but may actually be experiencing less objective sleep quality. However, the effect of sleeping with a partner on selection of sleep posture is not known. Controlling body and environmental temperature, so that thermal protective responses are not challenged is likely to minimise additional posture changes and consequently allow freedom of sleep posture selection.

2.5.6 Changing Sleep Posture

Actions to cause behaviour change can occur at an individual, community or population level (N.I.C.E, 2007). Patients presenting to health services with waking spinal symptoms are commonly asked about their sleep postures and provided with advice to avoid possible provocative sleeping postures. This approach appears to have sound clinical reasoning and biological plausibility. It has been demonstrated that an individual's daytime posture can be moderated through the use of external supports (Cannon & McGill, 2015; Hoe, Urquhart, Kelsall, & Sim, 2012; van Niekerk, Louw, & Hillier, 2012; van Poppel, de Looze, Koes, Smid, & Bouter, 2000) and postural education (O'Sullivan et al., 2006; Scannell & McGill, 2003). Following this line of logic, it is plausible that if certain sleeping postures provoke symptoms, then adoption of supports and education could be utilised as part of a strategy to alleviate waking symptoms. However, to utilise supports, postures to be avoided would need to be known and this has not been clarified for all sleep postures. With regard to education, it is not known if individuals following sleep posture education can adopt the recommended sleep postures while asleep. These two possibilities of support and education will be further explored in the broader context of sleep literature.

2.5.6.1 External Support

2.5.6.1.1 Avoiding Sleep Postures

Devices to avoid certain sleep postures have been used for a variety of orthopaedic conditions; tennis elbow (Gorski, 2016, May), plantar fasciitis (Batt, Tanji, & Skattum, 1996), rotator cuff pathology (Gorski, 2018), pregnancy related carpal tunnel syndrome (Ekman-Ordeberg, Salgeback, & Ordeberg, 1987) and cubital tunnel syndrome (Assmus et al., 2011). As early as 1872, patients were being issued with mechanical devices to assist them to avoid supine because of snoring. More recently physical supports such as tennis balls, pillows, backpacks and bolsters, attached to the backs of sleepers, have been found to be beneficial in treating participants with positional OSA (Jokic, Klimaszewski, Crossley, Sridhar, & Fitzpatrick, 1999; Permut et al., 2010). A more sophisticated form of an external support is a gravity activated position monitor. In one study, male participants (N = 10) with positional OSA received training for 1 night using a chest monitor, that produced a noise if participants remained in supine for more than 15 seconds (Cartwright, Lloyd, Lilie, & Kravitz, 1985). Following training, participants were asked to continue sleeping on their side and were reassessed 3 months later. There was a significant reduction in the number of apnoeic events from 55 to 21 (t = 3.26, p < .01) and oxygen desaturations from 239 to 87 (t = 3.02, p <.02) following training due to a greater avoidance of supine. Another type of wearable support detects sleep posture using three accelerometers and utilised increasing degrees of vibration to alert the sleeper to a supine sleep posture (van Maanen & de Vries, 2014; van Maanen et al., 2012). This wearable support reduced time spent in supine from 21% to 3% after 6 months of use (Z = -6.25, p < .001) for participants with mild to moderate positional OSA.

In summary, these studies indicate that if a sleep posture has been identified as being provocative of symptoms and a device can detect this posture, it has been possible with training that participants can learn to avoid or minimise exposure to these sleep postures.

2.5.6.1.2 Supporting Sleep Postures

During sleep, spinal posture has been influenced through the use of pillows, (Desouzart et al., 2016; Gordon et al., 2009; Park, Kim, Lee, Han, & Hur, 1999), cushions (Chohan, Payne, Selfe, & Richards, 2013), mattresses (Jacobson, Boolani, Dunklee, Shepardson, & Acharya, 2010; Kovacs et al., 2003) and even a customised adapting base (Deun et al., 2012; Verhaert, 2011) in an attempt to provide optimal spinal alignment and reduce spinal symptoms. Optimal spinal alignment in supine is considered to occur when spinal alignment is similar to standing (Park, Lee, Hong, & Kim, 2001) and in side lying, when spinal alignment is approximately a straight line in the frontal plane (Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011). Healthy participants (N = 106) slept for 1 week each on their own pillow and five experimental pillows (polyester, foam regular, foam contour, feather, and latex). Participants recorded daily retiring and waking symptoms, sleep quality and pillow comfort ratings. During the study, regular waking symptoms, failure to relieve retiring symptoms, poor pillow comfort and poor quality of sleep were reported by over 50% of participants. As a result, the authors recommended the use of a polyester or latex pillow and to avoid feather pillows (Gordon & Grimmer-Somers, 2010). In a follow-up study, the authors noted that participants with pillows less than 18 months old had no pain symptoms (Gordon & Grimmer-Sommers, 2011). Sleep posture was not objectively evaluated.

In a systematic review examining mattress design in adults with and without lumbar pain, it was concluded that a subjectively identified, medium-firm and custom inflated mattress, was optimal for spinal alignment, symptom relief and quality of sleep (Radwan et al., 2015). However, when evaluating a customised sleep system with healthy participants, it was concluded that sleep quality was influenced more by sleep posture than by the customised sleep system (Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011). Participants that spent more time in side lying and prone, experienced poorer sleep than those that slept longer in supine and side lying. The interplay between pillow, mattress and base is complex with many possible variables. It would seem that the reason why participants experience waking symptoms cannot be attributed to only their sleeping system.

2.5.6.2 Education

Clinical experience and research indicates that postural education can elicit postural changes when conscious (Scannell & McGill, 2003) and while asleep (Murayama, Kubota, Kogure, & Aoki, 2011). Intuitively it would seem more challenging to implement postural changes while asleep, however, it is known that during and immediately after a change in posture, people are in an increased state of arousal (Hobson, 2005). It is possible that during this state of increased arousal, self-evaluation and correction of sleep posture could occur.

In four studies, changing sleep posture with education was used as an intervention to alleviate spinal symptoms or improve quality of sleep (Desouzart et al., 2015; Desouzart et al., 2016; Goldman, 2005; Miller, 1984). In a series of case reports, participants (N = 23) with a variety of spinal symptoms, and identified through self-report as prone sleepers, were instructed to improve their sleep posture (Miller, 1984). No physical treatment was provided until an improved sleeping posture was achieved. However, what an improved sleep posture entailed and how this was taught, was not described. It was noted by the author that establishing a normal sleeping posture could take months, but more commonly only 1 month. Outcomes reported were based on time frame (up to 6 months) and symptom changes. Seventy four percent (n = 17) achieved a satisfactory rating and two others improved, but not sufficiently. It was noted that three of the four who did not improve were older than 40 years of age. No validated outcome measures were used to measure symptoms or sleep posture changes. Goldman (2005), provided 11 participants with both spinal stenosis and diabetes, specific day (usage of a walker to induce lumbar flexion) and night (sleep postures of reclined upright, supine with pillow placed under the knees or side lying with the pillow between knee) postural education to minimise lumbar extension. Following this postural education, nine of the 11 participants reported moderate to excellent improvements in day and night symptoms. For six of these, improvements occurred within 1 day. No baseline or follow-up objective assessment was undertaken to confirm sleeping postures in these participants, nor was any method used to validate compliance with the recommended postures.

In the only study in this group of four to objectively assess sleep posture (using IR videography), 24 participants were divided evenly into three groups to assess changes in sleep quality (Desouzart et al., 2015). The three groups were Intervention, Placebo and Control. The method of allocation was not reported. All participants were videoed for 3 nights (2 nights being scored) at baseline and at follow-up which was between 3 and 4 months later. The Intervention group received an initial sleep posture lecture which encouraged supine and symmetrical side lying postures with pillow support with material presented being sent and weekly ‘positive’ follow-up via phone and email. Participants in the Placebo group received education about relaxation training and participants and ‘informal’ contact via phone and email, while participants in the Control group received a ‘moment’s interview’ and no follow-up contact. There was a reported significant change in sleep posture in the Intervention group but it is unclear which sleep posture(s) this change relates to. No reliability or validity data were reported for the sleep posture scoring method. There was also a reported change in the Placebo group (p = .009), but again the change was not related to a specific posture (e.g., prone increased from 26% to 30.1% while supine decreased from 30.2% to 24.4%). There were no significant changes in the Control group. It is difficult to draw firm conclusions from this study, due to a lack of reported allocation of participants, non-reporting of reliability or validity data of the sleep posture scoring method, variable follow-up between groups and lack of clarity in statistical analyses.

In a pilot study by the same authors, 20 female seniors were divided into two groups, Intervention and Control (Desouzart et al., 2016). The method of randomisation was not reported. The main outcome measure reported was pain, using a VAS. The Intervention group received sleep posture education encouraging the adoption of supine and symmetrical side lying postures, using pillow support and how to get in and out of bed. After a period of 4 weeks, the pain VAS was re-evaluated in both groups. Baseline pain VAS was higher in the intervention group (M = 5.40, SD = 2.01) compared to the control group (M = 4.30, SD = 2.36). After the intervention phase there was a significant reduction in pain VAS (M = 3.00, SD = 1.63, p = .009). There was a non-significant change in the control group pain VAS (M = 3.90, SD = 3.21, p = .472). Between groups comparisons were not reported, possibly because it was a pilot study. We used an online calculator (Centre for Evaluation and Monitoring, 2018) to determine an effect size with 95% confidence intervals between groups, using baseline to post intervention data in two steps. Baseline to post intervention change was used because a significant difference between groups existed at baseline. Firstly, a pooled standard deviation for each group was calculated for change from baseline to final measure. Then this pooled standard deviation from each group was used to calculate the between group effect size 0.81 (95% CI: -0.11, 1.72). The resultant confidence interval indicates that significant differences between groups was unlikely. Further, while the Intervention group had a significant reduction in pain, the premise it was due to an improvement in sleep posture cannot be confirmed because no objective assessment of sleep posture was performed at baseline or after the intervention period.

Sleep posture education has also been used to modify symptoms associated with positional OSA. Three studies are reported here. In an early study, four male participants with positional OSA were identified using PSG. The participants were advised to avoid supine and were reviewed between 4 months and 3 years later. Two participants also used a ball in a sock and the type of education was not specified. Polysomnography was used on review and it was noted they all spent less overall time in supine. All participants subjectively reported marked improvements in daytime alertness and decreased daytime sleepiness over the period of reassessment. (Kavey et al., 1985).

In a later study, two previously effective techniques used to reduce positional OSA, were compared (N = 60) by using four groups of randomly selected participants (Cartwright et al., 1991). All groups were instructed in good health habits for sleep apnoea which included (a) lose (or maintain) weight by controlling diet; (b) exercise at least 20 minutes a day, (c) use no alcohol after 6 pm and (d) learn to sleep on the side and avoid the supine-sleeping position. One group used a chest alarm, another group used a tongue retaining device, a third group used both devices and the final group was only told the good health habits. After an 8 week period, during which all participants were contacted weekly, participants were re-examined using PSG again over two nights. All groups had significant reductions in the amount of time spent in supine:

- Chest alarm M = 141, SD = 76 to M = 3, SD = 9 (t = 7.42, p < .01)
- Tongue retaining device M = 145, SD = 83 to M = 70, SD = 75 (t = 2.84, p < .02)
- Both M = 116, SD = 71 to M = 3, SD = 11 (t = 5.91, p < .01)
- Good health habits M = 101, SD = 58 to M = 16, SD = 22 (t = 6.59, p < .01.)

In the good health habits group (n = 15), all participants improved and 10 out of the 15 did not sleep in supine at all. In comparison, only two out of 15 did not sleep in supine in the tongue retaining device group. Further, 11 in the good health habits group had weight reduction, whereas only five in the chest alarm, four in the tongue retaining and three in the both group achieved any weight reduction. The authors commented that "telling patients what they need to do to improve and telling them they would be tested to see how well they could do this, worked very well for most of these patients" (Cartwright et al., 1991, p. 551).

In a more recent study, eight self-aware snoring middle aged and elderly men were assessed using PSG in a sleep laboratory over 3 nights (Murayama et al., 2011). The first night was for adaption and participants could move freely. On the second and third nights, using a randomised crossover method, participants were instructed to avoid supine and attempt to sleep as much as possible in side lying. The authors reported an increase in time spent in side lying, during the intervention phase (M = 42.1%, SD 12.5%, p < .012) and no significant change in number of posture changes. A single person evaluated all the sleep posture data and no validity or reliability data were reported for the classification of sleep postures, but it would seem in combination with the other studies examining positional OSA, that participants following education are able to change the selection of their sleep postures.

Overall, posture education has been used to elicit changes in the sleep posture choices of participants to reduce spinal symptoms, improve quality of sleep and reduce episodes of positional OSA. Intervention periods have ranged from 4 weeks to 3 years, with a variety of follow-up methods and frequencies. In several studies, no objective sleep posture data were collected. In other studies that uses PSG to collect sleep posture data, no reliability or validity data were presented. In summary, while multiple studies indicate the ability for education to change sleep posture, the lack of use of validated and reliable measures of sleep posture, limits the conclusions that can be drawn about the ability for education to change sleep posture choices.

2.5.6.3 Adherence to Change

Sleep is a repeated event and participants have a regular routine of sleep postures that varies little from night to night. See Section 2.5.1. While the presentation of waking onset symptoms represents an acute presentation, the underlying sleep routine is habitual, and changing a habit would require a longer-term consideration. There is no definitive period of time to develop a new habit, but it is known that adherence to a new exercise program is approximately 65% (McGrane, Galvin, Cusack, & Stokes, 2015), indicating that even with a combination of education and understanding about the beneficial effect of the new habit, maintaining a new habit is difficult. In a study in which participants with mild to moderate OSA, used a wearable support to alert them to a sustained supine sleep posture, subjective compliance (i.e., wearing device for 4 hours or more per night) after 1 month was 92%, after 3 months 74% and after 6 months 60% (van Maanen & de Vries, 2014; van Maanen et al., 2012). It is likely that maintaining a new sleep posture habit, even with the positive affirmation of less waking spinal symptoms could be likewise challenging.

2.5.7 Summary of Section 2.5 Sleep Posture

In this section, elements of sleep posture were explored with respect to an individual's development of a sleep posture routine, non-technological and technological methods of measuring sleep posture, classification of sleep posture, factors influencing chosen sleep postures, and the ability to change and maintain a changed sleep posture routine.

Individuals develop a sleep posture preference from an early age and this remains fairly consistent from night to night. Methods used to measure sleep posture were initially associated with serious sleep pathologies, however more recently interest in sleep systems and OSA, have led to the development of new technological methods to assess sleep posture. These methods are largely used in research laboratories, activate a first night effect, are expensive and have limited access. Traditionally sleep posture has been classified as supine, side lying and prone with adults spending the greatest amount of time in side lying. It makes sense to sub-classify this broad grouping into supportive and provocative side lying, based upon plausible spinal loads. Prone is generally considered provocative. Self-report has commonly been used to classify sleep postures, but is considered unreliable and has not been validated for sub classified side lying sleep postures. There are many factors that influence a chosen sleep posture, many of which are identifiable and modifiable. The use of external supports has enabled participants to change sleep posture, but provocative sleep postures need to first be identified. Education has also enabled participants to change their sleep posture and as a result, this simple intervention has potential to influence sleep posture routines and associated waking spinal symptoms.

2.6 Chapter 2 Key Points

Sleep

- Sleeping entails repeated stages of non-REM and REM sleep
- Non-REM sleep is associated with deep, recovery sleep and REM sleep with dreaming
- Posture shifts are strongly linked with transition into REM sleep and short periods of awakening

Anatomy, Biomechanics and Symptoms

- Active and passive spinal structures resist external forces of elongation, shear and torque. All tissues consist of collagen.
- Lying down sleeping, creates a low compression environment in which there is a greater neutral zone and greater load on passive restraint spinal tissues (e.g., IVD, ligaments and joint capsules)
- Sustained loads or repeated low loads cause collagen to deform in a known response called the stress-strain curve. The amount of deformation is influenced by the collagen's stiffness
- Collagen deformation varies with age, gender, ethnicity, genetic disorders, previous injury and temperature
- Repeated or sustained loads on innervated spinal structures may cause pain. Extension may compromise IVD nutrition and subsequent repair
- Postures sustained for 10 minutes in vivo experiments, have caused muscles spasms
- Low loads sustained for 10 minutes have caused the production of pro-inflammatory chemicals in spinal ligaments

Sleep Posture

- Sleep posture routines vary from person to person, more that night to night. Poor sleepers change sleep posture more frequently than good sleepers
- Sleep posture is usually classified as supine, prone and side lying. Self-reported sleep posture is not accurate for key sleep postures
- Most time is spent sleeping in side lying, but this is not a homogenous classification in regards to plausible biomechanical tissue load. Side lying has been subclassified into supportive and provocative side lying based

on plausible tissue load

- Sleep posture can be influenced by other factors (e.g., medical conditions, sleeping system)
- Sleep posture can be changed with external supports and education

Chapter 3. Developing a Long-Term Method of Sleep Posture Assessment in the Home Environment

This chapter is adapted from the publication of two manuscripts. The first involving the development and testing of a valid and reliable recording method to capture and store high quality images of sleep posture, including sub-classified intermediate side lying postures, under varying light and bed cover situations in the home environment (Cary, Stirling, Collison, & Briffa, 2019). See Appendix 4. The second manuscript was a pilot study using the new recording method in the home environment to explore the first night effect, the accuracy of self-reported sleep posture and relationships between sleep posture and waking spinal symptoms (Cary et al., 2016). See Appendix 2.

3.1 Introduction

Daytime posture is considered a contributor to spinal symptoms (Kumar, 1990; Norman et al., 1998), while sleeping is generally considered a period for rest and recovery (Cabot & Beckham, 2005; Helmanis, 2006). The most common adult sleep postures are side lying, supine and prone (De Koninck et al., 1992; Gordon et al., 2004; Haex, 2005). Side lying is the sleep posture that greater than 60% of European adults adopt for the majority of the night (De Koninck et al., 1992; Gordon et al., 2004; Haex, 2005). Some people wake with spinal symptoms not present when going to sleep (Goldman, 2005; Gordon et al., 2007b; Miller, 1984) and it is clinically postulated that some sleeping postures involving sustained, end range spinal rotation and or extension, may provoke pain sensitive spinal tissues (Goldman, 2005; Miller, 1984). For this reason, side lying has been sub-classified into intermediate postures based on plausible spinal load. See Section 2.5.2.2. At present there is no high-level evidence to support these clinical observations, due in part to the lack of an appropriate method to measure sleep posture. Self-report has commonly been used, but is considered unreliable as participants are unconscious and error rates of 33% have been reported (Hurwitz et al., 2018; Kaplowitz et al., 2015). A recent systematic review identified the need for non-invasive, low cost and user friendly objective measurements of sleep, that could be deployed into non-laboratory environments (van De Water et al., 2011). To be clinically applicable, the recording method to measure sleep posture needed to be robust enough to capture high quality images, under a wide variety of light and bed cover situations likely to occur in the home environment (Liao & Yang, 2008) and not provoke a first night effect. See Section 2.5.3.2.

In the next section, background information regarding the specific equipment selected to record sleep posture in the home environment is provided. In the subsequent section the reliability and validity of the new recording method is reported and in the final section the results of a pilot study where the recording method was field tested in the home environment are reported. The chapter finishes with a discussion and conclusion.

3.2 Equipment Selection and Parameters

3.2.1 Materials

Basic feasibility of the concept to measure sleep posture was discussed with Professor Peter Eastwood, from the Sleep Clinic at Sir Charles Gardiner Hospital, Perth Western Australia in September 2009. This discussion included a demonstration of the equipment used at the Sir Charles Gardiner Hospital Sleep Clinic and provided reassurance that the proposal was feasible. An Internet search and discussions with security providers was then undertaken to identify appropriate equipment specifications for night-time recording, to enable unobtrusive data collection in the home environment.

To enable viewing in low light and no light situations, IR technology can be utilised to provide illumination whilst minimising disturbance to participants. To achieve this, units consist of a built-in IR illuminator with light emitting diodes producing light that is not visible to the human eye, and a camera to detect the IR illuminated image. Data capture was achieved with a digital video recorder and stored in an internal hard drive. Selection of equipment was based upon specifications, availability and cost. This equipment required a 240V mains power supply.

3.2.1.1 Cameras

Cameras selected were Sony IR High Resolution (Security Camera King Veilux SVD-60IR28L2812D www.**security**camera**king**.com). In sleep research laboratories, most images of sleep posture are captured simultaneously with PSG examination and obtained from one viewing angle, usually at the foot end of the bed. An historical criticism of IR captured images has been their poor quality and the subsequent difficulty to determine sleep posture. Images from one camera are two dimensional and have no depth. Determining the posture of a three-dimensional object like the leg, in relation to the other leg or trunk, is difficult when viewed from only one angle. For this reason, we trialled several dual camera setups.

Motion detection was activated in one camera. Motion detection sensitivity was set to high and applied to the total visual field of the camera using proprietary Security Camera King software. Each body movement detected by the camera constituted an event, with a separate date and time stamp. The second camera was set to continuously record and had hourly time stamps. Resolution for both cameras was set to 352 * 240 pixels. The resolution was a balance between image quality and size of recording. With this resolution, on average an hour of continuous recording was 1.8 gigabits. While both cameras had auditory recording capabilities, no sound data were collected.

Figure 15. Side by side cameras. Both images were in same viewing plane and provided no depth of field benefit.

Figure 16. Side and overhead cameras. To obtain improved depth of field camera viewing, visual planes were orientated 90 degrees to each other. However, in this setup lack of room and safety when exiting the bed at night made a side camera position impractical.

Progression of trialling dual camera positioning:

1) Mounted side by side (Figure 15)

2) Foot end and side positioned cameras. (Figure 16)

3) Foot end and side overhead cameras. (Figure 17)

After trialling several combinations, we found using two cameras with viewing angles at approximately 90 degrees to each other (i.e., one overhead and one-foot end), provided optimal viewing depth perception, sleep posture recognition, relative ease of setup in a standard bedroom configuration and minimal inconvenience to the participant when moving around the bedroom at night (Figure 17). Utilising two cameras also provided data collection security in the event of one camera failing. A computer monitor was used to ensure cameras were correctly aligned and correctly imaging all the required area of the bed.

3.2.1.2 Stands and Supports

Stands were designed to accommodate modern house construction (roof ceiling minimum 2.4 m) and portability, while being stable enough to support the weight of a camera. Commercially available alternatives, such as music industry boom mike stands were considered but were not suitable due to high cost, lack of strength and stability. For this reason, the author designed and used 50mm round Iplex plastic tube to construct collapsible stands, placed on 50 * 25 mm steel bases (Figure 17). These were constructed to facilitate easy disassembly, vehicle transport, and reassembly in participants' homes. The foot-end camera was set at a height of 1.8m and the overhead camera at 2.35 m.

3.2.1.3 Digital Video Recorder

Data capture was achieved using a DVR (Security Camera King Elite Series 16 Channel H2.64 www.**security**camera**king**.com) and stored on an internal hard drive. Camera proprietary software was used for playback. The settings for each camera were programmed via the digital video recorder (Figure 18).

3.3 Reliability and Validity of Sleep Posture Assessment

This section is adapted from a manuscript published in the journal WORK (Cary, Stirling, et al., 2019). See Appendix 4.

The aims of this study were to determine the reliability and validity of assessing sleep posture, including sub-classified side lying sleep postures, in the home environment under varying light and bed cover conditions.

3.3.1 Methods

3.3.1.1 Ethics

This study was approved by the Human Research Ethics Committee at Curtin University, reference PT0169 (Appendix 1). Written informed consent was provided by each health care professional prior to viewing the videos. Consent for the distribution and publication of images in this study and any additional related information was provided by the model.

3.3.1.2 Definition of Sleep Postures

The sleep postures used for this study (Figure 14) were defined as follows:

Figure 17. Foot end and side overhead. The combination of an overhead camera and foot end camera, provided both the optimal viewing angles for depth of field and practical placement in the majority of homes. Cables were secured to flooring in areas of foot traffic for safety.

Figure 18. Digital video recorder. A DVR was selected that allowed at least 2 cameras input.

1) **Supine**: head rotated left, right or neutral, chest facing the ceiling and legs either straight, bent or a combination.

2) **Supported side lying:** one of two sub classifications of side lying. In the training video it was called 'side lying', however the terminology was modified and to be consistent throughout the thesis, this posture was renamed supportive side lying. The head is rotated left, right or neutral, with the top thigh resting on or behind the bottom thigh. Classified as right or left determined by lower shoulder.

3) **Provocative side lying:** the other sub classified side lying sleep posture which was called ¼ prone in the training video, in which the head is rotated left, right or neutral, with the top thigh forward of the bottom thigh Classified as right or left determined by lower shoulder.

4) **Prone:** head rotated left, right or neutral, chest facing the floor and both legs straight.

3.3.1.3 Sleep Posture and Sleep Conditions

Six sleep postures were video recorded under six different sleep conditions.

The sleep postures tested were;

1) Supine

2) SSL left

3) SSL right

4) PSL left

5) PSL right

6) Prone.

The sleep conditions tested were;

1) Natural light with clothes only
2) Natural light with a sheet
3) Natural light with a sheet and duvet
4) IR with clothes only
5) IR with a sheet
6) IR with a sheet and duvet.

Video images of the six sleeping postures were captured simultaneously in two visual planes, using cameras at the foot end of bed and overhead. Each of the six sleeping postures were captured for each of the six sleeping conditions. The same model demonstrated each sleep posture and all video was captured in the model's bedroom. Figure 19 shows the model under a sheet, illuminated with IR, in the supine posture, from foot end (CAM 1) and overhead cameras (CAM 2).

Figure 19. Supine sleep posture from two viewing planes using infrared cameras with sheet. To determine a sleep posture, it was important that a combination of viewing angles and a high-quality image was available, to accurately determine the placement of trunk and legs.

3.3.1.4 Procedure

The order of the six sleep postures was randomised for each of the six sleep conditions. The sleep posture order for each sleep condition was then transcribed onto an audio recording. During videoing, the model demonstrated each sleep posture based upon the audio recording. Each of the six sleep postures was maintained for 10 seconds and on completion of the sleep posture sequence for that sleep condition (60 seconds of recording), the model returned to supine and placed their hands-on their head for 10 seconds to demonstrate the end of the sleep posture sequence for that sleep condition. This procedure was repeated for the five other sleep conditions.

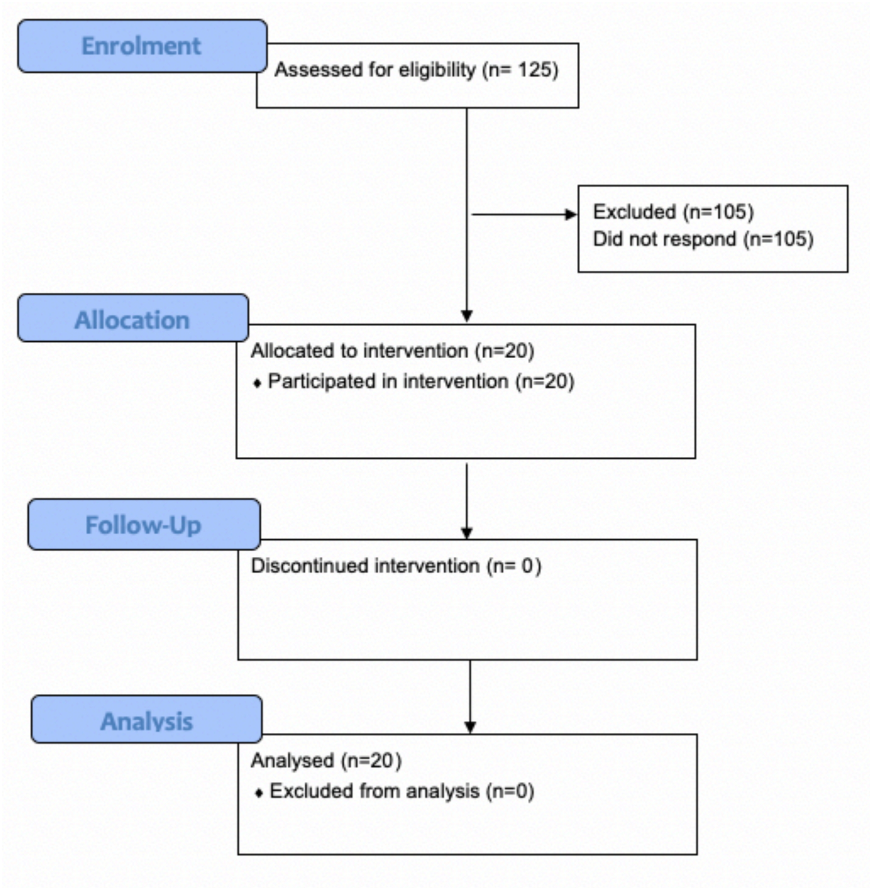

Figure 20. CONSORT Flow Diagram: Reliability and validity study

The recorded video was then imported into video editing software and a short training prologue section was added. This consisted of a picture of each sleep posture, with superimposed explanatory text describing the key features of the sleeping posture (supine, SSL, PSL and prone). Total video time was nearly 10 minutes, including the training section.

The Reliability and Validity Video was uploaded to a file sharing service and 125 health care professionals were invited to participate (Figure 20). Twenty were recruited by invitation and provided with personalised links see (Reliability and Validity Video). While the training video demonstrated six sleep postures, participants did not have to identify right and left as we were only interested in correct identification of the sleep posture. The professionals were asked to identify each of the 36 sleep postures as supine, SSL (right and left were combined), PSL (right and left were combined) or prone and email their completed Reliability and Validity Recording Sheet to the researcher (Appendix 3). The health professionals viewed the video on two separate occasions, with at least a two-day interval between viewings.

3.3.1.5 Data Analysis

Inter-rater reliability was determined using Fleiss's Kappa, comparing the concordance of classifications made by the 20 health professionals during their first viewing of the recorded postures under different lighting and bed conditions. Intra-rater reliability was analysed using Cohen's Kappa, comparing the classifications made by each professional during their first and second viewings of the recorded postures. Validity was determined using Cohen's Kappa comparing the classification by each of the 20 professionals during their first viewing of the video against the known posture of the model.

3.3.1 Results

3.3.1.1 Reliability of Posture Classification

Twenty health professionals (18 physiotherapists, 2 chiropractors; 12 female) with between two and 42 years of clinical experience (*M* = 16.7, *SD* = 12.4), viewed the uploaded recording twice.

Inter-rater and intra-rater reliability were excellent. Cohen's Kappa for intra-rater reliability was .93 (95% CI = .80, 1.0) with a value of 1.0 for 25% of the health professionals and Fleiss Kappa for inter-rater reliability was .83 (95% CI = .82, .84).

3.3.1.2 Validity of Posture Classification

Concordance between the health professionals' classification and the known posture was excellent, Cohen's Kappa was .91 (95% CI = .77, 1.0).

3.4 Pilot Study: Sleep Posture and Waking Spinal Symptoms

This section is adapted from a manuscript published in the Journal of Sleep Disorders: Treatment & Care (Cary et al., 2016). See Appendix 2.

3.4.1 Methods

3.4.1.1 Procedure

Fifteen participants were recruited through word of mouth, information flyers in medical clinics and an article in the local paper over a period of 16 weeks (Appendix 2). The procedure was explained and if volunteers agreed to participate, a recording date was agreed. There were no exclusion criteria (Figure 21).

On the arrival of the researcher, participants completed a Consent Form (Appendix 6) and a Pre-Sleep Questionnaire (Appendix 7). When completing the Pre-Sleep Questionnaire, participants nominated the percentage time of each night they spent in each of the four sleep postures and the frequency and location of morning symptoms experienced in the past month. Camera stands, cameras and other equipment were assembled in the sleeping area of the participant. Both cameras were set to record from 2000 to 0800 hours.

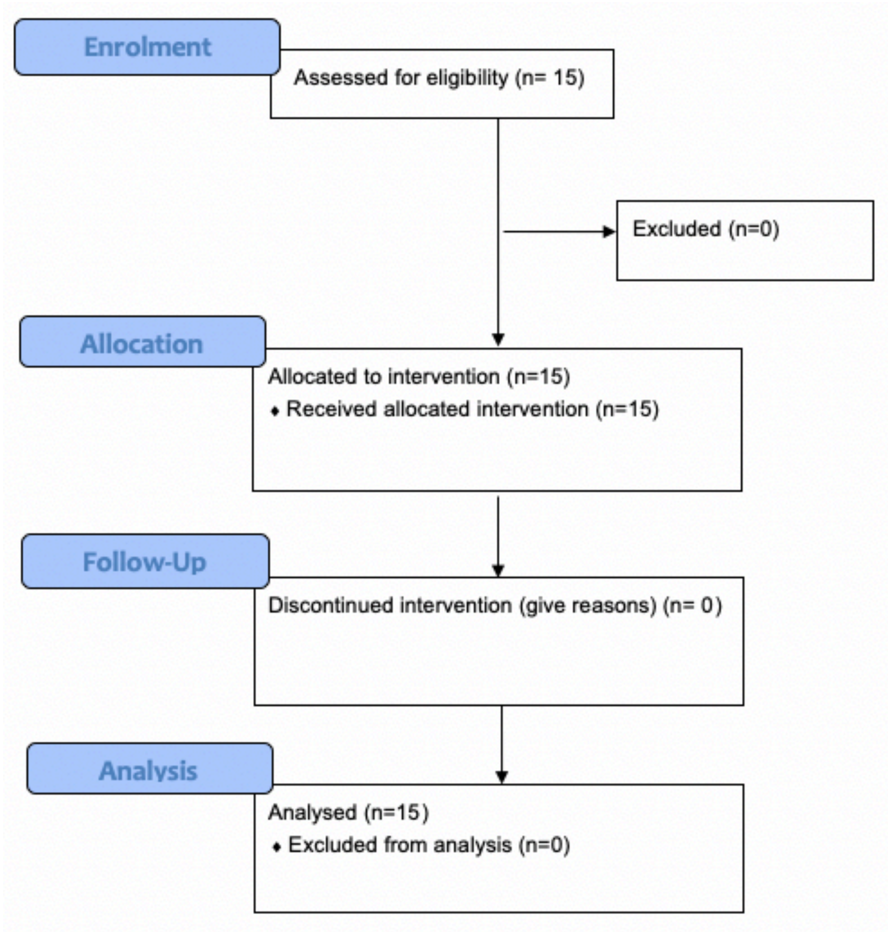

Figure 21. CONSORT Flow Diagram: Pilot study

The aims of this pilot study were to examine the utility of the new recording protocol in the home environment, to examine the accuracy of self-report of sleep postures, including sub classified side lying sleep postures and to examine relationships between sleep posture and waking spinal symptoms.

Camera alignment, zoom and focus were adjusted to accommodate the room size and bed orientation. This made analysis easier as it ensured when viewing data files from both cameras simultaneously, that the bed head was at the top of each picture frame and sufficient field of view was available on all sides of the bed (Figure 22). Participants were encouraged to maintain normal pre-sleep routines. After two nights equipment was retrieved.

3.4.1.2 Data Analysis

3.4.1.2.1 Video Recording

Video data were reviewed on the digital video recorder, using proprietary software. Head, trunk and leg postures were noted and the overall sleep posture was categorised according to the defined sleep posture. Each posture change and time stamp were noted manually on a data-recording sheet, accurate to the closest half minute (Appendix 8). Arithmetical errors were detected when reviewing calculated sleep posture totals as part of the intra-rater reliability study. Errors were due to manual calculation of sleep posture total times. Data were subsequently transferred to Excel to automatically sum sleep posture totals.

3.4.1.2.2 Intra-rater Reliability of Sleep Posture Classification

To determine intra-rater reliability of sleep posture classification in minutes, video recordings from Night 1 were first classified (i.e., Night 1a) using the posture definitions in Figure 14. Then in random order and with an interval of at least 2 weeks, Night 1 classifications were duplicated (i.e., Night 1b). The reliability analysis of sleep postures from Night 1a and Night 1b were performed using the intraclass correlation coefficient (ICC). The ICC statistic and the 95% confidence interval (95% CI) were reported.

3.4.1.2.3 First Night Effect

To determine whether there was a first night effect, differences in the time spent in each of the four sleeping postures between Night 1b and Night 2 were compared using the paired samples t-test ($p < .05$).

3.4.1.2.4 Accuracy of Self-Report of Sleep Posture Classification

To enable comparisons with self-reported sleep posture percentage data, the minutes per night in each posture and total sleep time were averaged across Night 1b and Night 2 and then expressed as a percentage for each sleep posture. Comparisons between self-reported sleep posture and actual sleep posture were made using the independent samples t-test ($p < .05$).

3.4.1.2.5 Relationship Between Sleep Posture and Waking Symptoms

To enable comparisons between waking symptoms and sleep postures, participants reported the number of mornings per month they woke with spinal pain and/or stiffness, in the following groups; 0, 1 - 3, 4 - 6, 7 - 10, and > 10 mornings per month. To ensure there were sufficient numbers in each cell, these categories were collapsed into three groups; no morning symptoms, one to three mornings per month and four or more mornings with symptoms per month. The average

Figure 22. Synchronised camera orientation. The orientation of the cameras was adjusted so that the bed head was at the top of both screens and there was sufficient viewing of the bed to enable posture determination.

percentage of the night spent in each posture (Night 1b and Night 2) were then compared between the three groups using the independent samples Kruskal-Wallis test.

3.4.1.3 Ethics

Ethics approval was provided by Human Research Ethics Committee of Curtin University (Approval Number PTO169). All participants provided written informed consent.

3.4.2 Results

Fifteen participants (8 female, *M* = 44.2, *SD* = 17.18 years of age, 87% sleeping with a partner) completed the Pre-Sleep Questionnaire and underwent two consecutive nights of video recording. Participants spent the greatest proportion of the night in supported side lying, followed by similar amounts in supine and provocative side lying and a minimal amount in prone (Table 1).

Table 1. Percentage of the night slept in each posture

	N	*M*	*SD*
Percentage in Supine	15	26.07	24.70
Percentage in SSL	15	41.34	24.09
Percentage in PSL	15	27.27	22.97
Percentage in Prone	15	5.32	7.25

Notes. SSL = Supportive side lying, PSL = Provocative side lying

3.4.2.1 Utility of a New Recording Protocol in the Home Environment

3.4.2.1.1 Utility of Video Recording

Equipment portability and setup was found to be relatively easy across a range of different sleep environments and acceptable to participants. Setup and checking of equipment took approximately 45 minutes. The motion detection camera picked up all changes in sleep posture, confirmed by the continuous recording camera. On average, it took twice as long to analyse sleep posture data from the continuous camera recording for one night (i.e., 60 minutes) than from the motion detection recording (i.e., 30 minutes). This time efficiency occurred firstly, because of the ability to skip from posture change event to event, rather than having to fast forward through periods without movement on the continuous recording. Secondly, when repeatedly reviewing the same event to determine the correct sleep posture, returning to the automatic time stamp created by the onset of movement, was quicker than repeated rewinding the video to the start of the movement event. The use of two cameras enabled the capturing of images from different visual planes, which improved the ease of posture identification and provided an important source of data in case of a single camera malfunction.

3.4.2.1.2 First Night Effect

There was no first night effect using this recording protocol in the home environment, with only non-significant differences found in the time spent in each posture between Night 1b and Night 2 (Table 2).

Table 2. Mean differences in time spent in sleep postures for Night 1b and Night 2

Posture	*N*	*Mean Difference*	95% CI	*p*
Supine	15	15.40	- 19.8 to 50.6	.364
Supportive side lying	15	26.93	-21.9 to 75.7	.256
Provocative side lying	15	-21.33	-43.6 to 0.92	.059
Prone	15	-4.10	-34.3 to 26.1	.775
Total Sleep Time	15	16.90	-5.42 to 39.2	.127

Note. All measurements are in minutes

3.4.2.1.3 Intra-rater Reliability of Sleep Posture Classification

When duplicate analyses of night 1 occurred with at least a 2 week interval, the intra-rater reliability for all four sleep postures was excellent (Table 3).

Table 3. Intra-rater reliability of duplicate classification of sleep posture

Posture	*N*	*ICC*	95% CI
Supine	15	.95	.85 to .98
Supported side lying	15	.91	.76 to .97
Provocative side lying	15	.97	.91 to .99
Prone	15	.97	.90 to .99

3.4.2.2 Accuracy of Self-report of Sleep Posture Classification

The Pre-Sleep Questionnaire included a question asking for a self-reported estimate of sleep posture when the participant fell asleep and when they woke up. However, as time of falling asleep and time of waking up could not be verified, these data were not analysed.

Participants were also asked to self-report the percentages of the night they believed they slept in each sleep posture. These self-reported percentages were reliably associated with video measured percentages for supine, but not for supported side lying, provocative side lying or prone. When combining the self-reported SSL and PSL values to generate a single side lying score as is reported in other studies, a moderate ICC value was obtained (Table 4).

Table 4. Reliability of self-report compared with video measured sleep posture

Posture	*N*	*ICC*	95% CI
Supine	15	0.70	.32 to .89

Supportive side lying	15	0.33	-.20 to .71
Provocative side lying	15	0.48	-.02 to .79
Combined side lying	15	0.59	.11 to .84
Prone	15	0.31	-.23 to .70

3.4.2.3 Relationships Between Sleep Posture and Waking Symptoms

The frequency of morning symptoms per month (see Table 5) as reported by participants in the Pre-Sleep Questionnaire was divided into three groups; no pain (n = 3), 1 to 3 mornings per month (n = 8), and four or more mornings per month (n = 4). There were no significant differences between the frequency of waking morning symptoms per month and the average (Night 1b + Night 2) total amount of time (minutes) spent in any sleep posture (Table 5).

Table 5. Comparison between average total time in a sleep postures and frequency of waking symptoms per month

Average Time (minutes)	Group	*N*	*Median (IQR)*	*Kruskal-Wallis*	*p*
Supine	no pain	3	27.0 (1.5,)		
	1 - 3	8	101.5 (39.4, 221.8)		
	4+	4	100.8 (34.4, 197.5)		
	Total	15	97.3 (27.0, 200.0)	0.38	.832
Supportive side lying	no pain	3	384.0 (56.0,)		
	1 - 3	8	138.8 (114.4, 229.9)		
	4+	4	166.8 (142.0, 252.1)		
	Total	15	162.3 (123.8, 261.2)	1.77	.412
Provocative side lying	no pain	3	0.0 (0.0, 0.0)		
	1 - 3	8	150.3 (44.6, 263.4)		
	4+	4	171.3 (37.2, 199.6)		
	Total	15	132.3 (21.5, 193.8)	3.55	.170

Prone	no pain	3	0.0 (0.0, 0.0)		
	1 - 3	8	13.5 (0.0, 45.6)		
	4+	4	35.1 (0.0, 72.8)		
	Total	15	7.5 (0.0, 50.5)	1.58	.453
Combined SSL and supine	no pain	3	411.0 (356.0,)		
	1 - 3	8	273.9 (182.8, 371.9)		
	4+	4	267.5 (178.6, 429.3)		
	Total	15	280.3 (194.2, 411.0)	2.08	.352
Combined PSL and prone	no pain	3	9.0 (0.0,)		
	1 - 3	8	191.8 (81.3, 287.9)		
	4+	4	213.8 (51.06, 251.8)		
	Total		184.5 (29.0, 482.4)	3.27	.195

Notes. SSL= Supportive side lying, PSL = Provocative side lying

Similarly, when the average (Night 1b + Night 2) time slept in each posture was converted to a percentage of the total sleep time, statistically there were no significant differences between average time slept in a posture and a specific frequency of morning symptoms per month (Table 6).

Table 6. Comparison between average percentage amount of time in a sleep postures and frequency of waking symptoms

Posture	*N*	*Median (IQR)*	*Kruskal-Wallis*	*p*
Supine %	15	20.7 (5.4, 41.8)	0.26	.877
Supportive side lying %	15	32.6 (27.7, 58.2)	2.03	.363
Provocative side lying %	15	29.5 (4.2, 43.9)	3.58	.167
Prone %	15	1.4 (0.0, 11.1)	1.58	.453

However, visual inspection of boxplots (Figure 23 and 24) indicates that participants who spent a greater total amount of time or greater percentage of time in PSL or prone, experienced a greater number of mornings waking with symptoms per month.

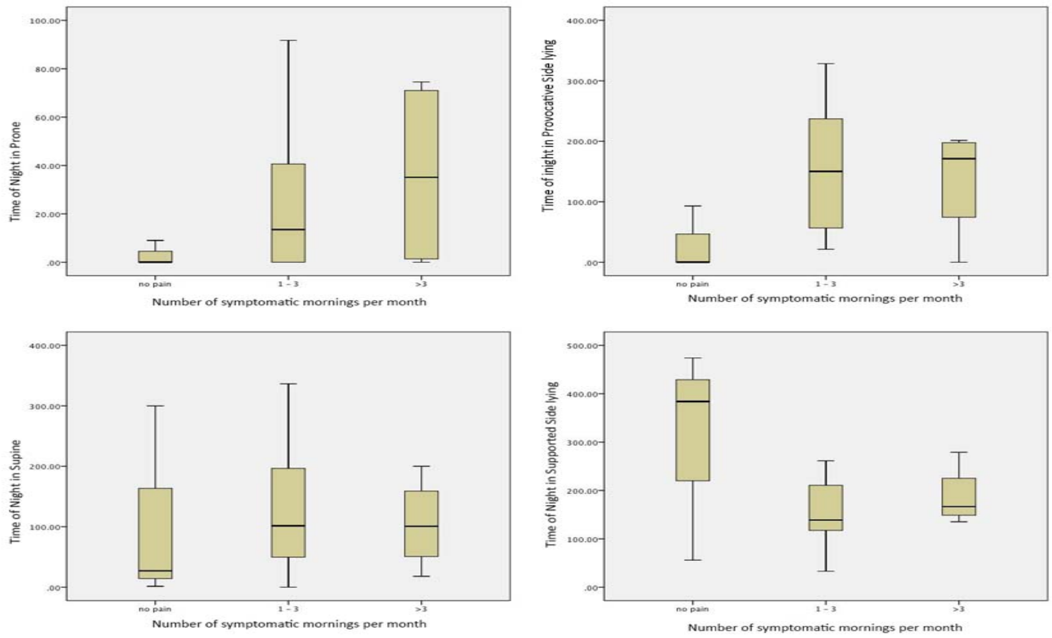

Figure 23. Average total time (minutes) spent in each posture relative to the number of mornings waking with spinal symptoms

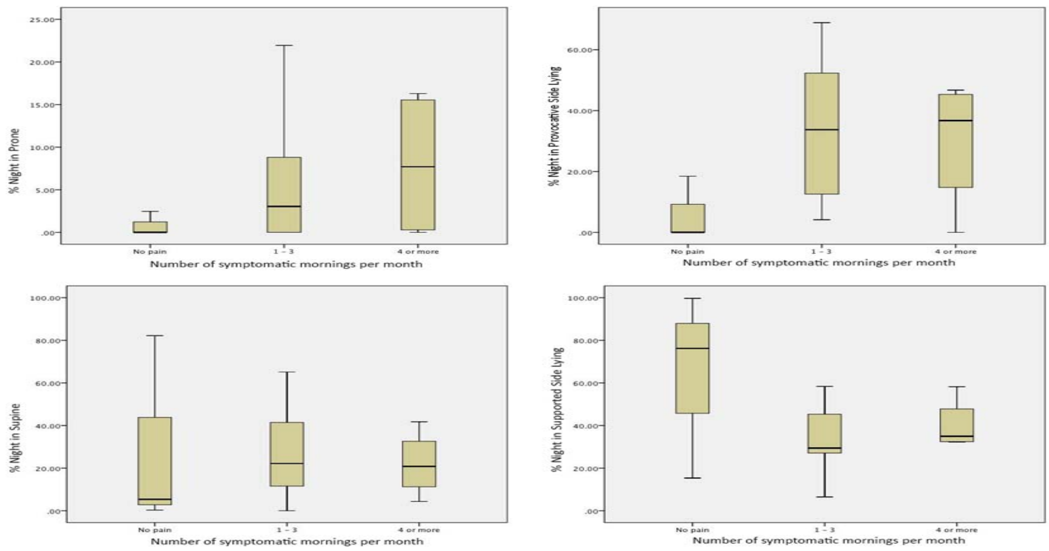

Figure 24. Percentage of time spent in each posture, relative to the number of mornings waking with spinal symptoms.

3.5 Discussion

The two studies reported in this chapter demonstrate the excellent levels of validity and reliability achievable when using two cameras as part of an unobtrusive and portable method to assess sleep posture, including intermediate side lying postures. Furthermore, the lack of a first night effect and high utility makes it an ideal, low cost method to assess sleep posture. Sample sizes were too small to find differences between time spent in sleep postures and waking spinal symptoms. However, visual inspection of boxplots suggests a relationship in that people who spent more time in provocative side lying or prone, experienced a greater frequency of waking spinal symptoms.

Reliability and validity results using this new method of sleep posture assessment compared favourably with other studies. When observing healthy participants in a temperature-controlled laboratory with photography, prior authors used a four-dimension classification system of sleep posture and reported an inter-tester reliability of over .8. Intra-tester reliability and validity were not reported (De Koninck et al., 1983). Other authors developed a computer algorithm that classified sleep postures into supine, side lying and prone, based on mattress indentation technology. The study was conducted in a sleep laboratory and the authors reported high reliability values of .9 for supine, and side lying and .8 for prone. They used a single camera video recording of sleep posture as the gold standard for comparison. However, no data were presented for the reliability or validity of using a single camera image as the gold standard to measure sleep posture (Verhaert, Haex, De Wilde, Berckmans, Vandekerckhove, et al., 2011). Neither study attempted to sub classify side lying into intermediate sleep postures, which are considered clinically important in regard to their influence on waking spinal symptoms. Nor did they undertake studies in the home environment. The 20 participants involved in our study examining the reliability and validity of sleep posture, received minimal training to observe and analyse sleep posture via videography. It is likely that accuracy would improve further with the provision of training, experience and feedback. Thesis objectives 1 (development of a recording protocol) and 2 (examining recording protocol validity and reliability) are addressed by these two studies and show that with the high degree of accuracy in measuring sleep posture in the home environment, this recording method has obvious benefits in relation to determining relationships between sleep posture and waking spinal symptoms. It also has potential clinical use in managing spinal stenosis (Goldman, 2003; LaBan et al., 1990), obstructive sleep apnoea (Itasaka, Miyazaki, Ishikawa, & Togawa, 2000; Kavey et al., 1985; Phillips et al., 1986), glaucoma (Kaplowitz et al., 2015), severe peptic oesophagitis (Harvey et al., 1987), and post-surgery or pressure relief positioning (Edlich et al., 2004; Schutz, 1941).

The ability of an individual to fall asleep and maintain their sleep varies enormously with the environment in which they are sleeping. Placed in a situation where the surrounds are different, such as a sleep laboratory, heightened levels of vigilance and arousal have been noted both in healthy and poor sleepers, and across a range of age groups (Kronholm et al., 1987). Called the first night effect, data from the first one or two nights are often excluded from analysis because of aberrant results. It has been found that the level of intervention (e.g., number of leads and attachments) relates to the severity of the first night effect. It was possible that noise from the computer cooling fans, camera LEDs, or the knowledge of being filmed might influence participants sleeping in their normal environment. However, in our second study which relates to thesis objective 3, no significant difference was found for any of the four sleep postures or total sleep time, indicating the equipment and awareness of being filmed did not impact on participants normal sleeping routine when in their home environment. Researchers and clinicians using this recording method therefore do not need to include any adaptive nights as part of data collection.

Similar to the findings from other studies, our participants spent the greatest period of time in side lying (after combining SSL and PSL), followed by supine and the smallest period of time was spent in prone (De Koninck et al., 1992; Gordon et al., 2004; Jacobson et al., 2010; Verhaert, Haex, De Wilde, Berckmans, Vandekerckhove, et al., 2011). To date, clinicians have largely relied on self-report from participants of their sleep posture to guide and assess interventions. Several clinical studies investigating the relationship between sleep posture and spinal symptoms have used self-report but provided no reliability or validity data confirming the accuracy of the self-report (Desouzart et al., 2016; Goldman, 2005; Gordon et al., 2004, 2007a; Marin et al., 2006). Others have used a single IR camera as the gold standard to determine the reliability and validity of self-reported sleep postures, but did not report the accuracy of the video gold standard (Gordon et al., 2004). Looking more broadly at self-report and sleep measures, participants with insomnia underestimated total sleep time, sleep latency and number of nocturnal arousals (Carskadon et al., 1976). In a classic study comparing self-reported “poor sleepers” with “good sleepers” using PSG, it was found that self-report “poor sleepers” actually slept much better than would have been expected based upon self-report (Monroe, 1967). In view of the plausibility that time spent in sustained rotation and extension could be provocative on spinal tissues (Section 2.3.2.3.4), we wanted to determine not only the accuracy of self-report for side lying generally, but also for the newly sub classified side lying postures. Participants in our study nominated the percentage of time they thought they slept in supine, SSL, PSL and prone. Comparisons made between self-report and video measured percentage of time were only accurate for supine. Similar inaccuracies of self-reported sleep posture have been recently reported by other authors (Kaplowitz et al., 2015; Yu, 2018). In relation to thesis objective 3, we found participants could not reliably report the proportion of the night spent in all sleeping postures, including intermediate slide lying postures, indicating the need for an alternative and more reliable measure of sleep posture.

Side lying is generally considered protective of spinal symptoms (Desouzart et al., 2016; Gordon et al., 2007a). It is also the sleep posture in which most people spend most of the time (De Koninck et al., 1992). In this small sample of convenience, we found no statistical relationship between individual sleep postures and morning symptoms. The trend however, was that participants who spent greater periods of time in SSL had fewer mornings with symptoms per month than those who slept in

PSL, indicating the possible importance of sub classifying side lying. The lack of statistical significance might be due to the small sample size or a mismatch in time frames. Participants were asked about their symptom frequency over the preceding month, but video data were only collected for two nights. It is possible for some participants, that the nights recorded were not representative of nights that caused their waking symptoms. It would be beneficial in future research to include a brief questionnaire completed first thing in the morning that would capture relevant time sensitive information, like the degree of morning symptoms and previous night's sleep quality.

There were two notable differences in these studies when compared to previous studies. Firstly, because of the wide variety in biomechanical loading of the spine during side lying, these studies looked at the ability to sub classify and correctly identify intermediate side lying postures. Using this method, intermediate postures in addition to the classical sleep postures of supine and prone, can be correctly identified in the home environment. This is an important step to better understanding possible relationships between sleep postures and waking spinal symptoms. Secondly, to our knowledge, this is the first study to have utilised a dual IR camera system to record sleep posture. As the majority of previous research was carried out in temperature-controlled environments, participants would usually only sleep under a light sheet, making posture assessment significantly easier. The use of dual cameras in our studies, was an important feature to achieve accurate visualisation of sleep posture without provoking any first night effect. In the technically challenging home environment, occasional instances of pets, children and camera failure, highlighted the importance of data collection from separate sources. While more cameras might be beneficial, it could become physically problematic and potentially intimidating in most modern bedrooms.

A possible limitation of the reported reliability and validity study, is that the model recorded was filmed sleeping alone. While in sleep laboratory research this is also the norm, in the home environment, sleeping with a partner would be common and may influence sleep posture in two ways. Firstly, determining the accuracy of sleep posture is influenced by bed coverings. When sleeping with a partner the coverings will assume contours not solely conforming to one body shape, possibly obscuring limbs and making posture analysis more difficult. However, in the pilot study intra-rater reliability was very high in situations of both solo or partner sleeping. Secondly, it has been reported that sleeping with a partner induces more shifts in posture than when sleeping alone (Aaronson et al., 1980; Pankhurst & Home, 1994). It is not known however, if sleeping with a partner influences the sleep postures chosen. As we were primarily interested in measuring sleep posture, not posture changes in the home environment, we considered it more important to maintain a regular sleep routine and not separate couples.

3.6 Conclusion

The described recording method, utilising dual IR illuminated recording technology to collect valid and reliable sleep posture data in two planes, provides clinicians with an unobtrusive and portable method of measuring sleep posture that does not evoke a first night effect. It has been demonstrated that health professionals with a range of experience and minimal sleep posture training can reliably classify sleep postures, including sub classified side lying sleep postures, under a variety of light and bedding conditions. Findings were non-significant, but participants who slept for greater periods of time in PSL or prone, had more mornings of symptoms per month than those who slept in SSL or supine.

3.7 Chapter 3 Key Points

- Excellent validity and reliability of sleep posture classification (i.e., supine, supportive side lying, provocative side lying and prone) has been demonstrated under different light and bed covering situations using a dual IR camera setup in the home environment
- Using this setup, no first night effect was detected
- Participants who spent more time in provocative side lying or prone, experienced a greater frequency of waking spinal symptoms.

Chapter 4. Relationships between Sleep Posture and Spinal Symptoms: Methods

4.1 Introduction

Research with a focus on posture has been conducted in association with sleep pathologies such as insomnia, positional OSA, restless legs (LaBan et al., 1990; Ravesloot, van Maanen, Dun, & de Vries, 2013; van Maanen et al., 2012)) and sleep systems (Hsia et al., 2009; Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011). Research examining the potential role sleep posture may have on waking spinal symptoms is however limited, with few studies reported in this area (Desouzart, Filgueiras, et al., 2014; Gordon et al., 2007a). Most recently, Desouzart et al. (2016) used education as an intervention to modify participants' sleep posture, in a group of female seniors (*N* = 20) with spine pain. However, no objective measurement of sleep posture was used at baseline or on follow-up to confirm sleep posture or whether it actually changed in response to the education intervention.

This chapter describes the use of the valid and reliable method to assess sleep posture reported in the prior chapter and examines relationships between sleep posture and waking spinal symptoms in the home environment. Expanding on the prior pilot study (*N* = 15) detailed in Chapter 3, the methodology of a larger baseline cross-sectional study (*N* = 53) and a subsequent longitudinal study (N=33) are described. In the cross-sectional study, relationships between sleep posture and waking spinal symptoms in participants a control group (*n* = 20), predominantly cervical (*n* = 13) and predominantly lumbar (*n* = 20) spine symptoms were compared. In the longitudinal study the two symptomatic groups were provided an education-based intervention with the aim of changing sleep posture, and reassessed at 4 and 16 weeks.

4.2 Trial Registry and Ethical Approval

Ethical approval was provided by Curtin University Human Research Ethics Committee on 15/7/2014 (HR 140/2014) (Appendix 9).

Both the cross-sectional and longitudinal studies were registered with the Australian New Zealand Clinical Trials Registry on 4/07/2014 (ACTRN12614000708651 and ACTRN12614000707662 respectively) (Appendix 10).

4.3 Participants

A total of 53 participants (36 female) who were recruited over a period of 2.5 years, were allocated on enrolment based on symptoms into one of three groups; Controls (*n* = 20, 16 female), Cervical (*n* = 13, 10 female) and Lumbar (*n* = 20, 10 female)

(Figure 26). Recruitment occurred in Esperance, a rural town of Western Australia through word of mouth, recruitment posters, radio interviews, letters to possible referrers and newspaper advertisements (Appendix 5). Past patients were approached to participate if they had not previously been treated for spinal symptoms. The initial goal was to enrol 30 participants in each group, but for several reasons, participant numbers were limited in the Control and Lumbar groups to 20 and in the Cervical group to 13. Only those in the symptomatic groups (Cervical and Lumbar $N = 33$) were invited to participate in the longitudinal study.

Volunteers were allocated to either the Cervical or Lumbar group depending on their self-reported dominant area of symptoms at enrolment. Symptoms of spinal pain, stiffness or bothersomeness needed to be greatest in bed or on rising, that largely settled within an hour, greater than or equal to 3 out of 10 on a NRS (Yang & Haldeman, 2016), and occurred four or more times per month. If symptoms were less frequent than four times per month, or were less than 3 out of 10, participants were allocated to the Control group. Volunteers could only be allocated to one group.

4.3.1 Exclusion Criteria

Volunteers that were less than 18 years of age, or greater than 46 years of age were excluded. The younger age was for legal consent reasons and the upper age to minimise the chances of confounding factors like increasing severity of spinal degenerative changes (Gore, 2001). Volunteers with medical conditions such as severe osteoarthritis, spinal stenosis, oesophageal reflux and late stage pregnancy or using devices such as breathing apparatus that prevented them from sleeping in all postures were excluded (Gordon & Buettner, 2009). Those with co-existing medically diagnosed inflammatory conditions or unremitting pain (e.g., rheumatoid arthritis, neuropathic pain) were also excluded. Volunteers using medically prescribed hypnotic or relaxant medications would have been excluded as these medications can alter frequency of posture changes as noted in Section 2.5.5.2. but none were excluded for this reason.

4.4 Measurements

4.4.1 General Information

Participants in all three groups (Control, Cervical and Lumbar) were emailed a link to a Survey Monkey questionnaire (Appendix 18) that enabled the online completion of a range of baseline information. The online survey took on average 20 minutes to complete and was divided into several sections including general information and patient reported outcomes.

The general information section collected data on;

- Age
- Gender
- BMI
- Medications
- Level of education
- Self-reported percentage of time in each sleep posture (Supine, SSL, PSL, Prone)
- In what spinal area(s) did they experience their waking symptoms
- NRS for pain, stiffness, bothersomeness and quality of sleep for the prior 2 weeks
- Number of mornings per month they experience waking symptoms

4.4.2 Patient Reported Outcome

Due to the vanguard nature of this sleep posture research, the aims of these studies were to collect a broad range of pain, functional, sleep and quality of life patient reported outcome (PRO) measures, so as to better understand possible relationships between sleep posture and waking spinal symptoms. In each domain at least two commonly utilised measures were included. For example, in the sleep domain both the Insomnia Sleep Index (ISI) and the Pittsburgh Sleep Quality Index (PSQI) were used. The ISI is quicker to complete, and groups participant into four insomnia categories. The PSQI takes longer and participants are divided into poor and good sleepers. However, it also provides other information like sleep efficiency, reasons for poor sleep and day time functioning.

The same email link to participants as noted in Section 4.4.1., enabled online completion of a range of NRS and questionnaires, selected to examine relationships between sleep posture and spinal symptoms, disability, quality of sleep, and quality of life.

4.4.2.1 Numerical Rating Scales

Numerical rating scales for waking pain, stiffness, bothersomeness and quality of sleep in the prior 2 weeks were included. Higher scores indicated increased symptoms for pain, stiffness and bothersomeness and better quality of sleep.

The minimal clinical important difference (MCID) in a group of patients with non-specific neck pain was 2.5 points (Pool, Ostelo, Hoving, Bouter, & de Vet, 2007), with cervical radiculopathy it ranged from 0.4 to 2.1 (MacDowall, Skeppholm, Robinson, & Olerud, 2018). The MCID was 1.2 points in a group of lumbar surgery patients (Copay et al., 2008) and 1.5 points at 4 weeks follow-up in a group of patients with LBP (Childs, Piva, & Fritz, 2005). In a group of patients with rheumatoid arthritis a MCID of 0.6 for quality of sleep was found significant (Wells, Li, Maxwell, MacLean, & Tugwell, 2007). We could find no calculated MCID scores for bothersomeness and stiffness, however a 1.5 MCID estimate has been used for bothersomeness as an outcome measure for participants with cLBP (Sherman, Cherkin, Erro, Miglioretti, & Deyo, 2005).

4.4.2.2 Roland-Morris Disability Questionnaire (RMQ)

A 24-item, immediate recall self-reported lumbar disability measure, found to be reliable, valid and responsive to change over time. Higher scores indicated greater disability. In groups of participants with acute and subacute pain, and RMQ, MCIDs were found to vary depending on baseline measurements. In a group of LBP patients with baseline scores of 0 – 8, a MCID of 2 was considered significant (Stratford, Binkley, Riddle, & Guyatt, 1998). Others have reported a reduction of 30% from baseline measurement as significant (Jordan, Dunn, Lewis, & Croft, 2006). No permission is required for the use of this questionnaire.

4.4.2.3 Neck Disability Index (NDI)

A 10-item, self-reported questionnaire for cervical disability with good reliability (Pearson's $r = .89$, $p < .05$). Concurrent validity is .69 with the McGill Pain Questionnaire and .60 with VAS (Vernon & Mior, 1991). Higher scores indicate greater disability. The MCID in a group of patients with non-specific neck pain was 3.5 points (Pool et al., 2007). No permission is required for the use of this index.

4.4.2.4 Spine Functional Index (SFI-10)

A 10-item, 2 weeks recall whole of spine functional measure, the SFI-10 demonstrated high criterion validity with the Functional Rating Index ($r = .87$), equivalent internal consistency ($\alpha = .91$) and a single-factor structure in patients with spinal pain referred to physiotherapy clinics by medical practitioners (Feise & Menke, 2010; Gabel, Melloh, Burkett , & Michener, 2013). The SFI-10 demonstrated suitable reliability ICC = .97 and responsiveness (standardised response mean = 1.81). The Flesch-scale reading ease was 64% and user errors were 1.5%. A lower percentage indicates greater disability. A minimal detectable change (90% CI) was 1.7 points for the cervical spine and 1.5 points for the lumbar spine (Gabel et al., 2013). Permission has been granted by the developer to use this index.

4.4.2.5 Hospital Anxiety and Depression Scale (HADS)

A 14-item, two domain assessment widely used to identify cases of anxiety and depression in non-psychiatric hospital clinics for adults greater than 16 years of age (Zigmond & Snaith, 1983). There are two subscales, anxiety (HADS-A) and depression (HADS-D). Each item is scored on a 4-point Likert scale (0 - 3) generating anxiety and depression scores ranging from 0 to 21. Each score is categorised as a non-case (0 - 7 points), a borderline case (8 - 10 points) or a case (≥ 11 points). The correlations between the two subscales varied from 0.40 to 0.74 (*M* = 0.56). Cronbach's alpha for HADS-A varied from 0.68 to 0.93 (*M* = 0.83) and for HADS-D from 0.67 to 0.90 (*M* = 0.82) (Bjelland, Dahl, Haug, & Neckelmann, 2002). It was found that the HADS performed well in assessing the symptom severity of anxiety and depression in somatic, primary care, the general population (Bjelland et al., 2002) and those with acute LBP (Turk et al., 2015). No MCID for pain related populations was found. A MCID in pulmonary participants is around 1.5 points or 20% of baseline score (Puhan, Frey, Büchi, & Schünemann, 2008). No permission is required to use this scale.

4.4.2.6 Insomnia Severity Index (ISI)

A 7-item, 2 weeks recall self-reported scale designed to assess the nature, severity and impact of insomnia and to monitor treatment response in adults (Bastien, Vallieres, & Morin, 2001; Morin, Belleville, Belanger, & Ivers, 2011). Scale development included a heterogenous group of patients with insomnia secondary to pain conditions (Smith, Perlis, Smith, Giles, & Carmody, 2000). Each item is scored on a 5-point Likert scale (0 = not at all, 4 = extremely likely), generating a total score (range 0 - 28). Total scores indicate severity of clinical insomnia, 0 - 7 points = no clinically significant insomnia, 8 - 14 points = subthreshold insomnia, 15 - 21 points = moderate clinical insomnia, 22 - 28 points = severe clinical insomnia. Internal consistency (α = .90) and face and content validity correlated with sleep diaries, PSG and interviews. A cut-off score of 10 had 86.1% sensitivity and 87.7% specificity for detecting insomnia cases in a community sample and a cut off level of 14 has optimal sensitivity (94%) and specificity (94%) in distinguishing a group of adults diagnosed with primary insomnia from those without (Smith & Trinder, 2001). A change score of six represents a clinically meaningful improvement in those with primary insomnia (Yang, Morin, Schaefer, & Wallenstein, 2009). The ISI has been validated as a web-based questionnaire. Permission was granted to use by Dr Morin.

4.4.2.7 Pittsburgh Sleep Quality Index (PSQI)

A 19-item, 7-domain, 2 weeks recall self-reported questionnaire which examines subjective sleep quality, with global scores ranging from 0 to 21. The PSQI has good psychometric properties with both internal consistency and test–retest reliability in the .80 range (Backhaus, Junghanns, Broocks, Riemann, & Hohagen, 2002), and excellent stability measured over a 1 year period (Knutson, Rathouz, Yan, Liu, & Lauderdale, 2006). Researchers using the PSQI, have demonstrated the ability to differentiate among a number of patient populations with varying sleep quality, convergent and discriminant construct validity (Carpenter & Andrykowski, 1998) and the PSQI is responsive to treatment aimed at improving sleep (Eadie et al., 2013). A global PSQI score greater than 5 is considered a poor sleeper and yielded a diagnostic sensitivity of 89.6% and specificity of 86.5% (kappa = .75, $p < .001$) in distinguishing between good and poor sleepers. Higher scores indicate poorer sleep quality (Broderick, Junghaenel, Schneider, Pilosi, & Stone, 2012; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). A change score of 3 is argued to be clinically significant (Buysse et al., 2011). Permission was granted to use by Dr Buysse.

4.4.2.8 Medical Outcomes Study 36-Item Short-Form version 2 Health Survey (SF36v2)

The Short Form-36 is a well-validated health-related quality of life measured. Version 2 (1 week recall) is available and was used with Australian normative data (Marin, Taylor, & Gill, 2009; Ware & Sherbourne, 1992). It yields an 8-scale profile of functional health and well-being, of which two standardised summary scores (i.e., Physical Component Score and Mental Component Score) can be calculated. A higher score is indicative of a better general health status. In lumbar spine surgery patients the MCID of the physical component is 4.9 points where the total possible score is 100 points (Copay et al., 2008) and changes between 3 and 5 points are accepted as clinically relevant (Frendl & Ware Jr, 2014; Norman, Sloan, & Wyrwich, 2003). License granted was granted by QualityMetric Health Outcomes ™ Scoring Software (QMo19116).

4.4.3 Video Night Measurements

Retrieved video data were reviewed on the network video recorder, using proprietary software. Head, trunk and leg postures were noted and the overall sleep posture (i.e., supine, SSSL, PSL and prone) was categorised according to the sleep posture definitions outlined previously (Figure 14). For some analysis, postures were also grouped into supportive, including supine and SSL and provocative, including PSL and prone, based upon plausible spinal load. See Section 2.5.4. Each posture change was manually recorded on a data-recording sheet (Appendix 8) relative to the time stamp and rounded up to the next half minute. For example, 31 to 59 seconds became a full minute and 1 to 29 seconds became a half minute. To be recorded, a posture needed to be sustained for at least 1 minute. Head movements from neutral to right or left rotation, without a change in trunk position were recorded, but were not considered a new posture because of no major change in load on the spine. If participants moved from right to left SSL or PSL, this was recorded and considered as a new posture, due to the major change in body posture and associated perceived spinal load. Sustained posture intervals of 30 minutes or greater without a major change in body posture were noted as a LPPI.

In addition to the collection of video data, participants completed a Morning After Questionnaire (Appendix 11) each morning after being videoed, to score pain, stiffness, bothersomeness and quality of sleep on a NRS in relation to the prior night.

4.5 Procedure

Participants enrolled in the cross-sectional study were contacted at two timepoints, enrolment and baseline assessment. Participants enrolled in the longitudinal study were contacted at four timepoints; enrolment, baseline assessment, 4 weeks assessment and 16 weeks after baseline assessment/intervention (Figure 25).

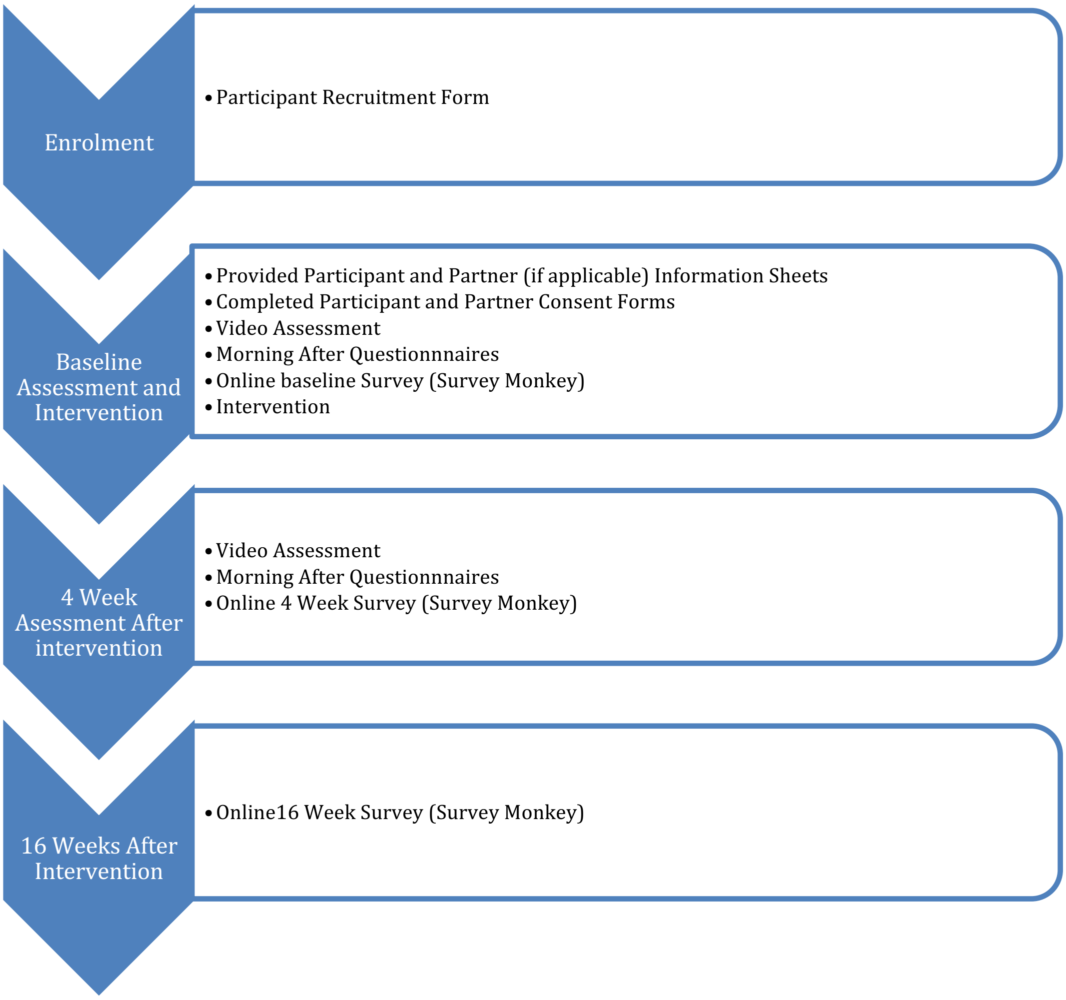

Figure 25. Flowchart of sleep posture intervention study

Volunteers were asked screening questions in an interview to determine eligibility for inclusion into the study (Appendix 12). All volunteers who were not excluded, were allocated using a process of best fit, to one of the three groups (Figure 26).

On acceptance into the study, the study procedure was explained in detail to each participant and a time to install equipment was arranged. Friday and Saturday nights, or other nights that were considered by participants to be unrepresentative of their normal sleep routine, were avoided when possible (e.g., changeover night from night shift to day shift). On arrival at the home of the participant, the researcher assembled the camera stands, mounted both cameras and installed the other related equipment, as described in Section 3.4.1.1. Equipment was checked for correct settings and imaging of appropriate visual fields. The necessary field of view was explained to the participant and a computer monitor was left in situ, so that participants could correct the imaged visual fields in case a camera was accidentally knocked.

Participants were given an information sheet explaining the study and their involvement (Appendix 13). If they slept with a partner, a separate information sheet was provided for the partner (Appendix 14). All participants and partners signed a participation consent form (Appendix 15 and Appendix 16). To capture details specific to each night's sleep, participants were provided with two copies of the Morning After Questionnaires (Appendix 11), in which participants reported if and where they experienced morning symptoms and rated their pain, stiffness, bothersomeness and quality of sleep, on a NRS from 0 to 10. An email link to their online baseline survey (Survey Monkey) was provided (see Appendix 18).

After two nights video recording equipment and the Morning After Questionnaires were collected.

Participants allocated to the Cervical or Lumbar groups, were then instructed on sleep postures believed to be supportive (supine and SSL) of the spine and postures believed to be provocative (PSL and prone) of the spine (Figure 14). This explanation included having the participant lie down on their bed in each supportive posture; supine, right SSL and left SSL with the researcher provided feedback until the participant had correctly obtained each posture. The researcher also explained why on the basis of plausible adverse spinal load, provocative sleep posture (right and left PSL and prone) were to be avoided. An educational handout reviewing the supportive sleep postures (Appendix 17) was provided to participants to assist future recall of the correct sleep postures. Participants were encouraged to adopt supportive sleep postures when going to bed and during arousal in the night for the following 4 weeks. No other follow-up was provided.

4.5.1 Four Weeks Post-Intervention Assessment

The online survey (Survey Monkey) and video data collection were repeated 4 weeks after the baseline timepoint. Installation of recording equipment was repeated for sleep posture reassessment and participants were provided with another email link to complete their 4 week post-intervention online survey. The questionnaire content was essentially the same as in the baseline survey (except for age, gender and level of education). All participants were filmed sleeping in the same bedroom, sleeping on the same sleep system, with the same partner as in their baseline recording. Participants were again provided with two copies of the Morning After Questionnaire for completion. Following completion of two nights recording, equipment and questionnaires were collected and participants were informed a link to their final online questionnaire would be emailed to them in 12 weeks.

4.5.2 Sixteen Weeks Post-Intervention Assessment

Using the provided email link, participants repeated the online survey (Survey Monkey) 16 weeks after baseline.

4.6 Data Analysis

4.6.1 Sample Size

A priori sample size calculations for this study were based on data collected from the 15 participants measured in the Pilot Study. See Section 3.5.2. Of these, three reported no spinal pain and four reported four or more episodes of spinal pain per month. Participants from the pain free group spent 8% of the night in prone and those from the pain group 32%. Standard deviation for the sample was 5%. In order to detect a difference of the same magnitude a sample of 30 in the pain free group and 60 in the pain group would have a power of 99% assuming a two-tailed p-value of 0.05. Further, a sample of 60 people with pain would have sufficient size to detect a clinically meaningful change in pain of 1.5 points on a NRS assuming a SD of 2 points, with a power of 99% or a clinically meaningful change of 5 standardised points on the SF36 summary scales assuming a SD of 10 points with a power of 96% following the intervention.

4.6.2 Data Collection Changes

Five participants were excluded from the cross-sectional data analysis (Figure 26). After completing baseline data collection, online questionnaire and video data 3 participants were excluded from the longitudinal data analysis;

- Participant ID 30 (Lumbar group) declined further involvement, stating they were no longer interested in participating (i.e., no 4 or 16 weeks online and no 4 week video data).
- Participant ID 9 (Cervical group) moved interstate after completing the baseline data (i.e., no 4 or 16 weeks online and no 4 week video data).
- Participant ID 8 (Cervical group) completed the 4 week video and Morning After Questionnaires, but not the online questionnaires and was uncontactable (i.e., no 4 or 16 weeks online data) (Figure 27)

Data collected using the online questionnaire were exported as a SPSS file and combined with video data. Questionnaires were scored according to published scoring algorithms or according to instructions provided by developers. Sleep data from Night 1 and Night 2 were averaged prior to further analyses.

Statistical analysis was performed using IBM® SPSS® v24.0. All data were checked for outliers by visual inspection of boxplots or population pyramids. Outlying data points were checked to ensure they were no data entry errors or measurement errors. This included checking of data scoring sheets and online questionnaires to confirm imported values were correct and there was consistency between Night 1 and Night 2 values.

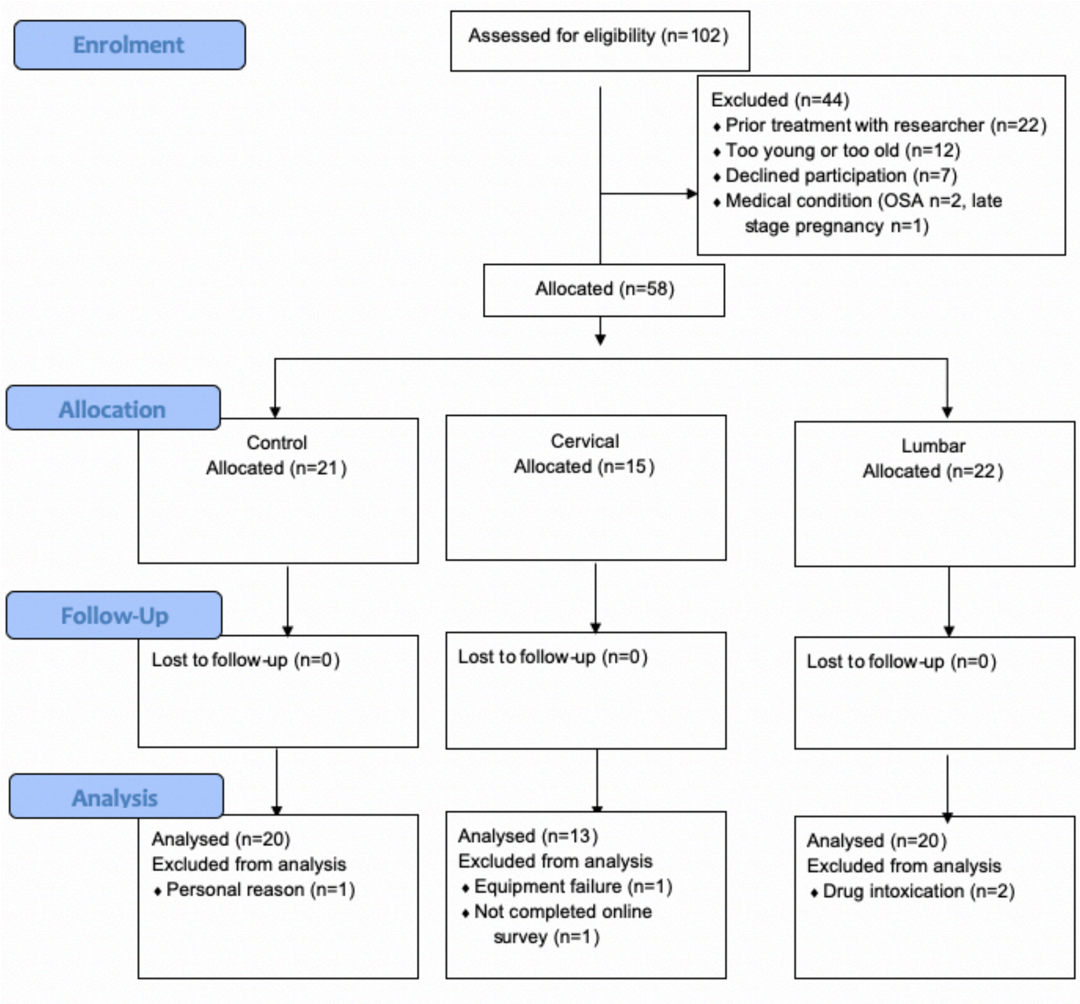

Figure 26. CONSORT Flow Diagram: Baseline study

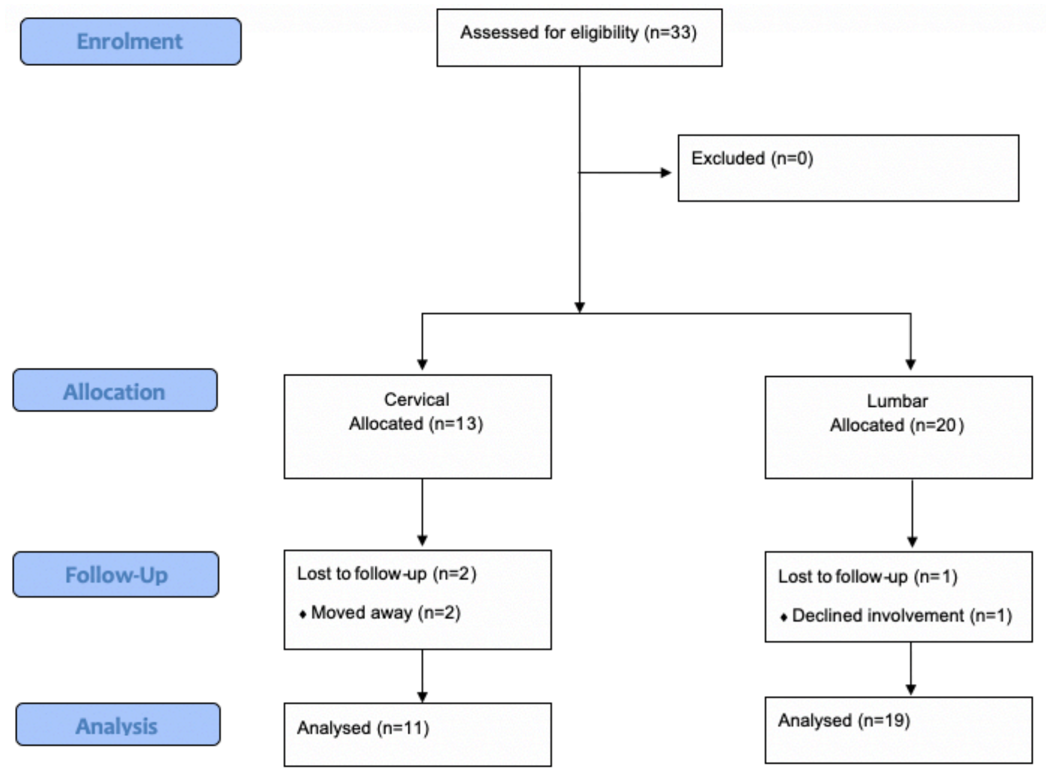

Figure 27. CONSORT Flow Diagram: Longitudinal study

On initial review of the raw video data for outliers within groups, it became apparent that while some participants were by definition sleeping in PSL (i.e., top thigh advanced forward of the bottom thigh, see Figure 14) because of the use of pillows and/or duvet providing top thigh support, participants technically did not induce spinal rotation or extension. For this reason;

- Participant ID 44 (Control group) who slept with a pillow under their thigh for both nights during what would typically be classified as PSL. Therefore, these periods were reclassified to SSL

- Participant ID 42 (Control group) slept in Night 1 for 96 minutes in PSL with a pillow under their thigh. This was reclassified to SSL.

- Participant ID 36 (Control group) was noted to spend in Night 1, 46 minutes in PSL and 44 minutes in prone, in both situations with a pillow under chest and trunk. The data were left as initially recorded as the lumbar spine was still rotated in PSL and while the lumbar spine was neutral in prone with the pillow support, the cervical spine was rotated. However, on Night 2, 26 minutes were spent in PSL with a double fold of duvet that neutralised spinal rotation. That period was reclassified to SSL.

Other changes were made because;

- Participant ID 37 (Control group) Night 1, both cameras were recording motion detected movements and it was noted the participant was asleep in PSL at 24:37hrs but on next motion detection activation at 01:02hrs, was in SSL, at 1:11hrs was in SSL and at 1:48hrs was in PSL, indicating the camera was not detecting all movements. For this reason, the time spent was averaged across both sleep postures for these time intervals.

Genuinely unusual values were rare and retained in the analyses.

Descriptive statistics were presented as count and percentage, mean (*M*) and standard deviation (*SD*) or median and interquartile range. The distribution of the data was examined using numerical (Shapiro-Wilk test) and graphical (visual examination of Histograms and Normal Q-Q Plots) methods. Achieving a normal distribution was difficult for the Control group in the baseline studies, particularly for the PRO variables as most participants in this group reported low or no symptom levels.

A $p < .05$ (two tailed where appropriate) was considered significant for all analyses. No corrections were made for multiple comparison as all hypotheses were developed prior to data analysis.

4.6.3 Cross Sectional Study

A chi-square test was used to compare categorical variables between groups. Intraclass correlation coefficient analysis was used to compare self-reported sleep posture (Appendix 18, Question 6 "In the last 2 weeks, what percentage (%) of the night do you spend in each position? Total to equal 100") with the actual percentage time spent in each sleep posture, gathered from averaging the two recorded nights' video data.

Intraclass correlation coefficient was used to compare 2 weeks prior waking spinal symptoms and quality of sleep (Appendix 18, Questions 10 – 13) with Morning After Video questionnaire waking spinal symptoms and quality of sleep (Appendix 11). The ICC statistic and 95% CI were reported.

After outliers and normality assumptions were checked, homogeneity of variance was checked using the Levene statistic for normally distributed data ($p > .05$ significant). Between group comparisons were undertaken using a one-way analysis of variance (ANOVA) statistic (F). For non-normally distributed data a Mann-Whitney U test (U) was undertaken to compare means or distributions.

4.6.4 Longitudinal Study

In general, to examine changes following the intervention, the paired samples t-test was used to compare between baseline and 4 weeks for sleep video data and the one-way repeated measures ANOVA statistic was used to compare between all three time points for each PRO. If distribution was normal, mean and standard deviation were reported, if not a normal distribution, then median and interquartile ranges were reported. When there were extreme outliers or there was a violation of the assumption of sphericity, a Friedman test was conducted to confirm the ANOVA analysis. Mauchly's test was used to examine the assumption of sphericity and where this assumption was violated ($p < .05$ significant) a Greenhouse-Geisser adjusted p value was reported. No corrections were made for multiple pairwise comparison as all hypotheses were developed prior to data analysis.

4.7 Chapter 4 Key Points

- The methodology of a cross sectional and longitudinal study are described
- In addition to sleep posture video data, a broad range of pain, functional, sleep and quality of life PRO measures were collected for both studies using an online survey instrument
- Volunteers are allocated into one of three groups based upon symptoms; Control, Cervical and Lumbar
- After collection of baseline data, participants in the Cervical and Lumbar groups received education on how to change their sleep posture and were evaluated again at 4 and 16 weeks after the intervention.

Chapter 5. Relationships between Sleep Posture and Spinal Symptoms: Results

5.1 Cross Sectional Study

5.1.1 Characteristics of Control, Cervical and Lumbar Groups

Fifty-three participants were recruited for this study, 20 participants each in the Control and Lumbar groups and 13 in the Cervical group. The age of participants ranged from 18 to 45 years, with the largest group of participants in the 41 to 45 years range (Table 7).

Overall there were more female than male participants, with 16 females in the Control group and 10 in both the Cervical and Lumbar groups. There were no significant differences in distribution of age or gender between groups (Table 7).

With regard to education, in the Control group the largest percentage of participants achieved postgraduate or higher education while in the Cervical and Lumbar groups the largest percentage obtained a trade qualification. In the Cervical group an equal proportion of participants obtained an undergraduate degree and an undergraduate degree. These variations were not statistically significant (Table 7).

Body mass index scores did not differ significantly (p = 0.632) between the Control (M = 26.86, SD = 4.95, 95% CI: 24.54, 29.17), Cervical (M = 25.93, SD = 3.20, 95% CI: 23.99, 27.86) and Lumbar (M = 25.75, SD = 4.03, 95% CI: 23.87, 27.64) groups. Baseline BMI categorical classifications are detailed in Table 7.

Table 7. Characteristics of sample

	Control	Cervical	Lumbar	Total	Value	*p*
Age						
18-20	2 (4%)	0 (0%)	1 (%)	3 (6%)		
21-25	3 (6%)	2 (4%)	4 (8%)	9 (17%)		
26-30	2 (4%)	1 (2%)	2 (4%)	5 (9%)		
31-35	3 (6%)	1 (2%)	1 (2%)	5 (9%)		
36-40	1 (2%)	6 (11%)	3 (6%)	10 (19%)		
41-45	9 (18%)	3 (6%)	9 (17%)	21 (40%)		
Total	20 (100%)	13 (100%)	20 (100%)	53 (100%)	11.3	.336
Gender						
Male	4 (8%)	3 (6%)	10 (19%)	17 (32%)		
Female	16 (30%)	10 (19%)	10 (19%)	36 (68%)		
Total	20 (38%)	13 (30%)	20 (38%)	53 (100%)	4.8	.092
Education						
High school	4 (20%)	1 (8%)	3 (15%)	8 (15%)		
Trade qualification	2 (10%)	4 (31%)	7 (35%)	13 (24%)		
Undergraduate degree	5 (25%)	4 (31%)	4 (20%)	13 (24%)		
Postgraduate or higher	8 (40%)	1 (8%)	4 (20%)	13 (24%)		
Other	1 (5%)	3 (23%)	2 (10%)	6 (11%)		
Total	20 (100%)	13 (100%)	20 (100%)	53 (100%)	9.9	.270
BMI						
Underweight (< 18.5)	2 (10%)	0 (0%)	0 (0%)	2 (10%)		
Normal (18.5, 24.99)	6 (30%)	5 (38)	10 (50%)	21 (40%)		
Overweight (25, 29.99)	8 (40%)	7 (54%)	7 (35%)	22 (42%)		
Obesity 1 and 2 (30+)	4 (20%)	1 (8%)	3 (15%)	8 (16%)		
Total	20 (100%)	13 (100%)	20 (100%)	53 (100%)	8.7	.366

5.1.1.1 Medication

Participants nominated the types of medications and supplements they were currently using. Approximately the same percentage in each group used no medications or supplements; Control group 60% (n = 12), Cervical group 46% (n = 6) and Lumbar group 65% (n = 13). Similar percentages in each group used one to two medications and supplement; Control 30% (n = 6), Cervical 30% (n = 6) and Lumbar 46% (n = 6), and respectively 10% (n = 2), 5% (n = 1) and 8% (n = 1) used three or more medications or supplements. The types of medications and supplements used in each group are detailed in Table 8.

Table 8. Medication and supplement use for all groups

Type of Medication	Control	Cervical	Lumbar	Total
Pain relief	0 (0%)	6 (15%)	2 (5%)	8 (20%)
Antidepressant/Anxiety	2 (5%)	3 (8%)	2 (5%)	7 (18%)
NSAID	1 (2%)	1 (2%)	1 (2%)	3 (8%)
Other*	12 (30%)	4 (10%)	6 (15%)	22 (55%)
Total	15 (38%)	14 (35%)	11 (28%)	40 (100%)

Note. Other* includes medications for birth control, anti-reflux, high blood pressure, high cholesterol, underactive thyroid, hay fever and mineral supplements

5.1.2 Accuracy of Self-Reported Sleep Posture

Participants' self-reported percentage of sleep in each of the main sleep postures was compared with the actual percentage of time participants spent in each sleep posture measured with video recordings. Correlations were poor within sleep postures (ICC < .34), indicating participants' self-report of sleep posture was not accurate (Table 9).

Table 9. Comparison of self-report and actual percentage of time spent in each sleep posture

Variable	*M*	*SD*	*ICC*	95% CI
Supine				
Self-report % supine	24.49	21.69		
Actual % supine	35.80	16.53	.25	-.02, .48
Supportive Side Lying				
Self-report % SSL	26.11	25.00		
Actual % SSL	38.52	17.20	.27	.00, .50
Provocative Side Lying				
Self-report % PSL	40.66	27.33		
Actual % PSL	21.94	19.07	.34	.08, .56
Prone				
Self-report % prone	8.74	16.68		
Actual % prone	3.74	5.79	.28	.02, .51

Note. SSL = Supported side lying, PSL = Provocative side lying

5.1.3 Consistency of Waking Symptoms and Quality of Sleep

At baseline, participants were asked to rate their waking spinal symptoms and quality of sleep in reference to the prior 2 weeks (Table 10). This was compared with their ratings provided each morning after recording their sleep posture using the Morning After Sleep questionnaire. Values from the two mornings were averaged for comparison. There were strong correlations for pain, stiffness, bothersomeness and quality of sleep, indicating the spinal symptoms and quality of sleep that occurred after the two videoed nights, were consistent with participants' usual waking symptoms and quality of sleep.

Table 10. Comparison of prior 2 weeks with waking spinal symptoms and quality of sleep

Variable	*M*	*SD*	*ICC*	*95% CI*
Pain				
Prior 2 weeks pain	2.77	2.28		
Average morning pain	2.37	2.21	.86	.77, .92
Stiffness				
Prior 2 weeks stiffness	3.40	2.37		
Average morning stiffness	3.19	2.34	.80	.68, .88
Bothersomeness				
Prior 2 weeks bothersomeness	3.43	2.30		
Average morning bothersomeness	2.82	2.37	.82	.71, .89
Quality of Sleep				
Prior 2 weeks quality of sleep	5.36	2.20		
Average morning quality of sleep	5.83	1.84	.70	.54, .82

5.1.4 Comparing Control and Cervical Groups

At baseline, participants were asked to nominate the area and frequency of their waking spinal symptoms and their sleep quality in reference to the prior 2 weeks. Participants also completed a range of patient reported outcomes online using a Survey Monkey link. Sleep posture data was collected from video recordings over two consecutive nights and values were averaged. Results comparing the Control and Cervical groups are presented in this section.

5.1.4.1 Distribution of Symptoms

Visual examination of Table 11 indicates participants allocated to the Cervical group experienced self-reported cervical symptoms more frequently than the Control group, however they also experienced symptoms in other spinal areas. One participant, (Cervical 4), nominated on enrolment cervical as the area of most symptoms, but in their baseline questionnaire, nominated mid back as the area of most symptoms over the prior two weeks. Participants in the Control group experienced symptoms in a range of spinal locations, but because the intensity was less than three out of ten or the symptoms they experienced occurred less than four times per month, they had been allocated to the Control group. See Section 4.3.

Table 11. Location of symptoms in prior two weeks in the Control and Cervical groups

Area of Symptoms	Control* (*n* = 20)	Cervical* (*n* = 13)
Nil	5	0
Neck	5	12
Mid back	3	3
Low back	9	3
Other	1	5

Note. * Participants in each group could nominate more than one area of symptoms, Other = Non-spinal area of symptoms e.g., knee

5.1.4.2 Frequency of Waking Symptoms

Visual inspection of Figure 28 shows that the majority of the Control group reported a much lower frequency of morning symptoms per month. To be included in the Control group, participants needed to experience morning spinal symptoms less than four times per month. This meant that some still experienced symptoms, but not frequently enough to be included into the Cervical group. The majority of participants in the Cervical group experienced morning symptoms nine or more times per month.

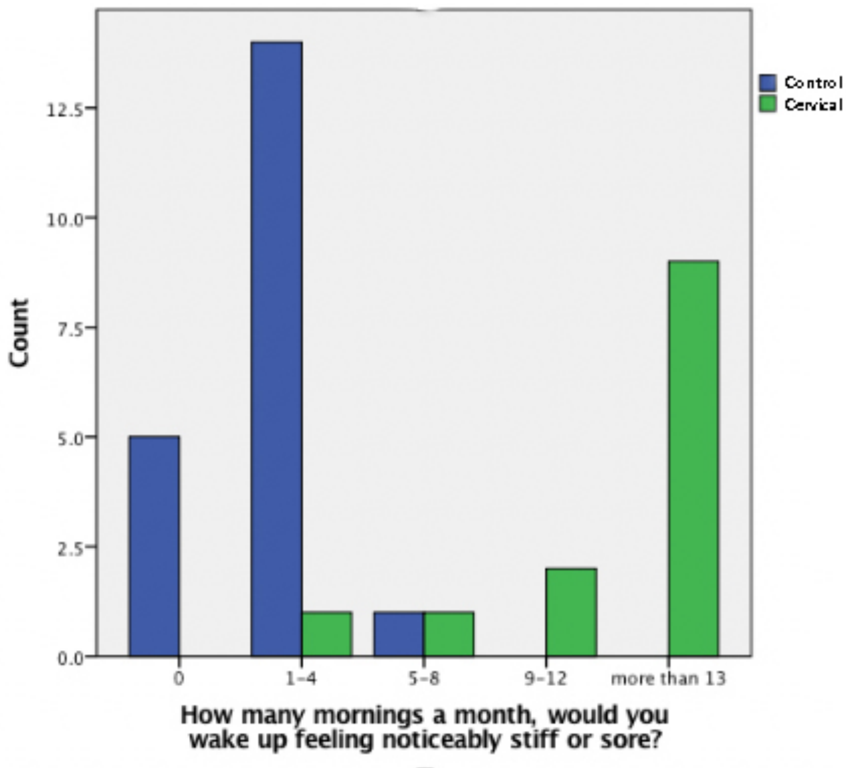

Figure 28. Frequency of morning symptoms at baseline between the Control and Cervical groups

5.1.4.3 Prior 2 Week Waking Symptoms and Quality of Sleep

At baseline, participants in the Cervical group self-reported significantly higher levels of all spinal symptoms and a significantly lower level of sleep quality in the 2 weeks prior to data collection (Table 12).

Table 12. Descriptive statistics and analyses of the prior 2 weeks symptoms in Control and Cervical groups

Variable	Control (*n* = 20)		Cervical (*n* = 13)		Analyses	
	Descriptives	Min/Max	Descriptives	Min/Max	*F/U*	*p*
Pain [b]	0.0 (0.0, 1.0)	0.0/4.0	5.0 (3.5, 6.0)	3.0/8.0	0.0[U]	< .001
Stiffness [b]	1.0 (0.0, 2.0)	0.0/3.0	5.0 (3.0, 6.0)	0.0/8.0	0.0[U]	< .001
Bothersomeness [b]	1.0 (0.0, 2.0)	0.0/4.0	6.0 (3.5, 7.0)	2.0/7.0	0.0[U]	< .001
Quality of sleep [a]	6.5 (2.1)	1.0/9.0	4.8 (1.7)	1.0/7.0	5.5[F]	.025

Notes. [a] = Mean (standard deviation), [b] =median (interquartile range), [F] = ANOVA statistic score, [U] = Mann Whitney statistic score

5.1.4.4 Patient Reported Outcomes

Due to the vanguard nature of the research investigating sleep, a range of disability, mental health, quality of sleep and quality of life PRO questionnaires were completed by participants at baseline.

Participants in the Cervical group recorded significantly poorer scores in all of the PRO questionnaires except the SF36 MS, when compared with the Control group (Table 15). This indicates participants in the Cervical group had higher disability as shown in the RMQ (even though is designed to measure acute and subacute lumbar spine pain) and NDI, and lower function as shown in the SFI. Participants in the Cervical group demonstrated higher levels of anxiety and depression. In regard to sleep quality, participants in the Cervical group scored higher in the ISI, but remained within the ‘no clinically significant insomnia’ group but would be classified as ‘poor sleepers’ using the PSQI classification. Participants in the Cervical group had poorer physical and mental health scores, with the physical score only being significant.

Table 13. Comparisons between the Control and Cervical groups across disability, sleep domains and quality of life measures at Baseline

	Control (*n* = 20)	Cervical (*n* = 13)	Analyses	
Variable	Descriptives	Descriptives	*F/U*	*P*
RMQ [b]	0.0 (0.0, 0.0)	2.0 (1.0, 3.5)	17.5 [U]	< .001
Spine Functional Index [b]	98.0 (93.0, 100)	86.0 (68.0, 94.0)	25.0 [U]	< .001
Neck Disability Index [b]	2.0 (0.0, 6.0)	18 (12.0, 26.0)	20.5 [U]	< .001
Insomnia Sleep Index [b]	3.0 (1.0, 4.0)	6.0 (4.5, 9.5)	54.0 [U]	.004
PSQI [a]	3.2 (1.6)	7.4 (4.1)	15.2 [F]	.002
SF36 PS [b]	69.3 (62.9, 71.8)	58.6 (52.4, 67.8)	192.0 [U]	.022
SF36 MS [b]	83.5 (78.6, 86.4)	80.0 (63.8, 84.45)	171.0 [U]	.137
HADS – Anxiety [a]	2.5 (2.3)	5.3 (2.8)	10.4 [F]	.003
HADS – Depression [b]	1.0 (0.0, 2.8)	3.0 (2.0, 4.0)	69.5 [U]	.024

Notes. [a] = Mean (standard deviation), [b] = median (interquartile range), [F] = ANOVA statistic score, [U] = Mann Whitney statistic score, F = ANOVA score, U = Mann Whitney score, RMQ = Roland-Morris Disability Questionnaire, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, SF36 PS = Short Form 36 Physical Score, SF36 MS = Short Form 36 Mental Score

Group means are presented in Table 15, but the PSQI and ISI questionnaires present their results as categorical variables. For this reason, separate tables have been prepared (Table 13 and 14). These tables demonstrate that participants in both symptomatic groups had poorer PSQI scores in comparison to the Control group and that while both groups had poorer ISI scores, they were only significant in the Lumbar group.

Table 14. Pittsburgh Sleep Quality Index in Control, Cervical and Lumbar groups

	PSQI		Chi Square	
Group	Good	Poor	Value	p
Control	19 (95%)	1 (5%)		
Cervical	5 (38%)	8 (62%)	12.7	.001
Lumbar	6 (30%)	14 (70%)	18.0	< .001

Note: PSQI = Pittsburgh Sleep Quality Index

Table 15. Insomnia Sleep Index in Control, Cervical and Lumbar groups

	Insomnia Sleep Index			Chi Square	
Group	No Insomnia	Subthreshold Insomnia	Clinical. Insomnia	Value	p
Control	17 (85%)	3 (15%)	0		
Cervical	7 (54%)	5 (38%)	1 (8%)	4.4	.112
Lumbar	7 (35%)	10 (50%)	3 (15%)	10.9	.012

5.1.4.5 Comparison of Sleep Posture Variables

5.1.4.5.1 Comparison of Percentage Time and Total Time in Sleep Postures

A range of sleep posture variables were extracted from the video data to examine possible relationships with waking spinal symptoms; specifically, the percentage of time and the total amount of time spent in each sleep posture (i.e., supine, SSL, PSL and prone) and the percentage of time and total amount of time spent in combined supportive (i.e., supine plus SSL) and combined provocative (i.e., prone plus PSL) sleep postures. See Section 4.4.3.

Participants in the Cervical group spent a greater percentage of the night in PSL (Table 16). When postures were merged into two categories, provocative and non-provocative, there were significant difference between groups in both categories. When time in each posture was expressed in absolute values, the Cervical group spent an average of three times as long in provocative side lying, this difference was again apparent when postures were merged into two categories.

Table 16. Comparisons between the Control and Cervical Groups in time spent in each posture, expressed as a percentage of the total time in bed (Percentage Time) or in minutes (Total Time)

	Control (*n* = 20)	Cervical (*n* = 13)	Analyses	
Variable	Descriptives	Descriptives	*F/U*	*p*
Percentage Time				
Supine [a]	39.2 (17.3)	32.8 (17.3)	1.2 [F]	.289
Supportive side lying [a]	43.0 (17.7)	31.2 (15.1)	3.6 [F]	.066
Provocative side lying [b]	16.0 (2.2, 22.4)	29.6 (12.7, 48.8)	187.0 [U]	.036
Prone [b]	1.9 (0.0, 4.0)	6.4 (0.0, 12.1)	175.0 [U]	.102
Supportive Combined [b]	82.2 (74.6, 96.0)	64.0 (49.3, 75.5)	141.0 [U]	.002
Provocative Combined [b]	17.8 (4.0, 25.4)	36.0 (24.5, 50.6)	210.0 [U]	.002
Total Time (minutes)				
Supine [a]	178.6 (75.9)	170.8 (85.1)	0.8 [F]	.785
Supportive side lying [a]	200.8 (91.6)	158.1 (83.1)	1.8 [F]	.185
Provocative side lying [b]	75.0 (10.2, 97.5)	153.0 (63.7, 242.5)	194.0 [U]	.018
Prone [b]	8.8 (0.0, 17.0)	32.1 (0.0, 59.5)	179.0 [U]	.074
Supportive Combined [a]	379.5 (326.2, 453.9)	328.9 (254.2, 396.2)	178.0 [U]	.118
Provocative Combined [b]	83.8 (16.4, 105.2)	185.1(118.0, 251.8)	212.0 [U]	.002

Notes. [a] = Mean (standard deviation), [b] = median (interquartile range), [F] = ANOVA statistic score, [U] = Mann Whitney statistic score

5.1.4.5.2 Duration of Sustained Sleep Posture

It was of interest to determine if there were any relationships between the number of posture changes (i.e., counted as a movement from one posture to another), number of LPPI and in what posture the LPPI occurred. If a posture was held for 30 minutes or more it was counted as one LPPI. See Section 4.4.3. We wanted to compare LPPI in the standard way (Standard LPPI) and also how many units of 30 minute intervals (Actual LPPI) accrued.

Participants in the Cervical group changed their sleep postures more frequently during the night (p = .029). The number of LPPI were not significantly different between the groups (Standard or Actual), however, participants in the Cervical group spent more of their LPPI in provocative sleep postures (Table 17).

Table 17. Comparison of posture immobility between Control and Cervical groups at Baseline

	Control (n = 20)	Cervical (n = 13)	Analyses	
Variable	Descriptives	Descriptives	*F/U*	*p*
# Posture changes [a]	18.3 (6.5)	23.6 (6.6)	5.2 [F]	.029
# Standard LPPI [b]	5.0 (3.6, 6.4)	6.0 (5.5, 6.5)	78.5 [U]	.057
# Actual LPPI [a]	7.8 (2.4)	8.3 (1.3)	0.4 [F]	.526
# Supportive LPPI [a]	6.6 (2.7)	5.5 (1.9)	1.5 [F]	.227
# Provocative LPPI [b]	0.5 (0.0, 1.5)	2.0 (1.5, 4.0)	59.5 [U]	.008

Notes. # = Number of, LPPI = Long periods of postural immobility, [a] = Mean (standard deviation), [b] = median (interquartile range), [F] = ANOVA statistic score, [U] = Mann Whitney statistic score

5.1.5 Comparing Control and Lumbar Groups

At baseline, participants were asked to nominate the area, frequency of their waking spinal symptoms and sleep quality in reference to the prior 2 weeks. Participants also completed a range of patient reported outcomes online using a Survey Monkey link. Sleep posture data was collected from videos recorded over two consecutive nights and values were averaged. Results comparing the Control and Lumbar groups are presented in this section.

5.1.5.1 Distribution of Symptoms

Visual examination of data in Table 18, indicates participants allocated on enrolment to the Lumbar group experienced self-reported waking lumbar symptoms more frequently than the Control group. As noted in Section 5.1.4.1., participants in the Control group did experience symptoms and in a range of spinal locations. However, because the frequency of symptoms was not sufficiently high, they were allocated to the Control group. Participants in the Lumbar group also experienced symptoms in a variety of spinal locations, with the majority of participants experiencing symptoms in their low back. Participants were allocated to the Lumbar group on the basis of best fit at enrolment because they nominated the Lumbar area as the area they experienced the most waking symptoms. See Section 4.5. The period of elapsed time between enrolment and collecting baseline data may be the reason why four participants allocated to the Lumbar group did not nominate low back as an area of pain in the prior two weeks, rather they nominated other area(s).

Table 18. Location of symptoms in the prior two weeks in the Control and Lumbar groups

Area of symptoms *	Control* (*n* = 20)	Lumbar* (*n* = 20)
Nil	5	0
Neck	5	4
Midback	3	6
Low back	9	16
Other	1	3

Notes. *Participants in each group could nominate more than one area of symptoms, Other = Non-spinal area of symptoms e.g., knee

5.1.5.2 Frequency of Waking Symptoms

Visual inspection of Figure 29 shows that the majority of the Control group reported waking symptom frequency of four or less times per month Reasons for why participants in the Control group experienced symptoms have been discussed in Section 5.1.4.2. The majority of participants in the Lumbar group reported waking symptoms of five or more times per month, although one person reported experiencing lumbar morning symptoms one to four times per month.

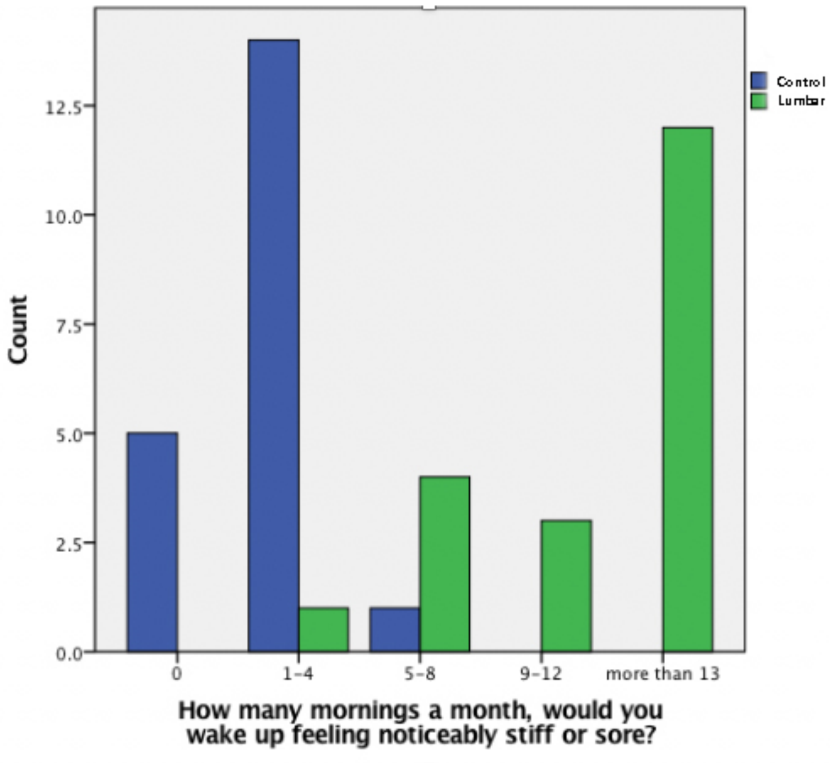

Figure 29. Frequency of morning symptoms at baseline between the Control and the Lumbar groups

5.1.5.3 Prior 2 Week Waking Symptoms and Quality of Sleep

At baseline, participants in the Lumbar group self-reported significantly higher levels of all spinal symptoms and a significantly lower level of sleep quality in the 2 weeks prior to data collection (Table 19).

Table 19. Descriptive statistics and analyses of prior 2 weeks waking symptoms in Control and Lumbar groups at Baseline

Variable	Control (*n* = 20)		Lumbar (*n* = 20)		Analyses	
	Descriptives	Min/Max	Descriptives	*Min/Max*	*F/U*	*p*
Pain [b]	0.0 (0.0, 1.0)	0.0/4.0	4.0 (3.0, 5.0)	0.0/7.0	44.4 [U]	< .001
Stiffness [b]	1.0 (0.0, 2.0)	0.0/3.0	5.0 (3.2,6.8)	2.0/7.0	10.5 [U]	< .001
Bothersomeness [b]	1.0 (0.0, 2.0)	0.0/4.0	4.0 (3.0, 6.0)	3.0/7.0	12.0 [U]	< .001
Quality of sleep [a]	6.5 (2.1)	1.0/9.0	4.6 (2.2)	1.0/9.0	8.2 [F]	.007

Notes. [a] = Mean (standard deviation), [b] =median (interquartile range), [F] = ANOVA statistic score, [U] = Mann Whitney statistic score

5.1.5.4 Patient Reported Outcomes

Participants in the Lumbar group recorded significantly poorer scores in all of the PRO questionnaires except the HADS - Depression, when compared with the Control group (Table 20). This indicates participants in the Lumbar group had higher disability as shown in the RMQ and NDI (even though is designed to measure disability associated with neck pain), and lower function as shown in the SFI. Participants in the Lumbar group demonstrated higher levels of anxiety. Sleep quality was reported as being poorer for participants in the Lumbar group. Participants scored higher in the ISI and would be classified as having 'subthreshold insomnia' and according to the PSQI would be classified as 'poor sleepers'. Participants in the Lumbar group had significantly poorer physical and mental health scores.

Table 20. Comparisons between Control and Lumbar groups across disability, sleep domains and quality of life measures at Baseline

	Control (*n* = 20)	Lumbar (*n* = 20)	Analyses	
Variable	Descriptives	Descriptives	*F/U*	*P*
RMQ [b]	0.0 (0.0, 0.0)	2.0 (1.0, 5.0)	29.0 [U]	< .001
Spine Functional Index [b]	98.0 (93.0, 100)	80.0 (62.5, 91.5)	28.5 [U]	< .001
Neck Disability Index [b]	2.0 (0.0, 6.0)	9.0 (4.5, 13.5)	70.0 [U]	< .001
Insomnia Sleep Index [b]	3.0 (1.0, 4.0)	10.0 (5.2, 11.8)	73.0 [U]	< .001
PSQI [a]	3.2 (1.6)	6.7 (3.1)	73.5 [F]	< .001
SF36 PS [b]	69.3 (62.9, 71.8)	59.9 (50.7, 68.8)	276.0 [U]	.040
SF36 MS [b]	83.5 (78.6, 86.4)	77.2 (68.9, 82.8)	275.0 [U]	.043
HADS – Anxiety [a]	2.5 (2.3)	6.4 (4.8)	11.8 [F]	.001
HADS – Depression [b]	1.0 (0.0, 2.8)	2.0 (0.2, 6.0)	149.5 [U]	.174

Notes. [a] = Mean (standard deviation), [b] =median (interquartile range), [F] = ANOVA statistic score, [U] = Mann Whitney statistic score, RMQ = Roland-Morris Disability Questionnaire, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, SF36 PS = Short Form 36 Physical score, SF36 MS = Short Form 36 Mental score

5.1.5.5 Comparison of Sleep Posture Variables

5.1.5.5.1 Comparison of Percentage Time and Total Time in Sleep Postures

As noted in Section 5.1.4.5.1., a range of sleep posture data including Percentage Time and Total Time in sleep postures was extracted. When sleep postures were combined, participants in the Lumbar group spent a greater percentage of time in provocative sleep postures and a greater amount of total time in provocative sleep postures, however these results were non-significant (Table 21).

Table 21. Comparisons between the Control and Lumbar groups in time spent in each posture, expressed as a percentage of the total time in bed (Percentage Time) or in minutes (Total Time)

	Control (*n* = 20)	Lumbar (*n* = 20)	Analyses	
Variable	Descriptives	Descriptives	*F/U*	*p*
Percentage Time				
Supine [a]	39.2 (17.3)	34.5 (16.8)	0.8 [F]	.380
Supportive side lying [a]	43.0 (17.7)	38.8 (16.1)	0.6 [F]	.431
Provocative side lying [b]	16.0 (2.2, 22.4)	23.0 (6.6, 33.6)	251.0 [U]	.174
Prone [b]	1.9 (0.0, 4.0)	3.9 (0.0, 5.3)	219.0 [U]	.620
Supportive Combined [b]	82.2 (74.6, 96.0)	73.1 (63.6, 92.0)	133.0 [U]	.072
Provocative Combined [b]	17.8 (4.0, 25.4)	26.9 (8.0, 36.3)	267.0 [U]	.072
Total Time (minutes)				
Supine [a]	178.6 (75.9)	164.0 (70.9)	0.4 [F]	.531
Supportive side lying [a]	200.8 (91.6)	193.2 (88.8)	0.1 [F]	.792
Provocative side lying [b]	75.0 (10.2, 97.5)	115.3 (34.6, 186.8)	256.0 [U]	.134
Prone [b]	8.8 (0.0, 17.0)	19.2 (0.0, 24.8)	219.0 [U]	.620
Supportive Combined [a]	379.5 (326.2, 453.9)	357.2 (301.1, 447.6)	172.0 [U]	.461
Provocative Combined [b]	83.8 (16.4, 105.2)	134.6 (40.8, 199.0)	272.0 [U]	.052

Notes. [a] = Mean (standard deviation), [b] = median (interquartile range), [F] = ANOVA statistic score, [U] = Mann Whitney statistic score

5.1.5.5.2 Duration of Sustained Sleep Posture

Participants in the Lumbar group changed their sleep postures more frequently during the night (non-significant) and while they had similar Actual LPPI, they spent more LPPI in provocative sleep postures (non-significant) (Table 22).

Table 22. Comparison of posture immobility between Control and Lumbar groups at Baseline

	Control (*n* = 20)	Lumbar (*n* = 20)	Analyses	
Variable	Descriptives	Descriptives	*F/U*	*p*
# Posture changes [a]	18.2 (6.5)	22.9 (9.1)	3.5 [F]	.071
# Standard LPPI [a]	5.2 (1.6)	6.0 (1.5)	2.7 [F]	.108
# Actual LPPI [b]	8.5 (6.0, 9.4)	8.5 (6.0, 9.9)	186.0 [U]	.718
# Supportive LPPI [b]	6.8 (5.1, 8.5)	6.0 (4.1, 8.1)	224.5 [U]	.512
# Provocative LPPI [b]	0.5 (0.0, 1.5)	1.5 (1.5, 3.4)	144.0 [U]	.134

Notes. # = Number of, LPPI = Long periods of postural immobility, [a] = Mean (standard deviation), [b] =median (interquartile range), [F] = ANOVA statistic score, [U] = Mann Whitney statistic score

5.2 Longitudinal Study

5.2.1 Cervical Group Comparisons

In this section the responses of the Cervical group to the sleep posture education intervention will be reported.

5.2.1.1 Have the Video Characteristics of Sleep Posture Changed?

Following the postural education, participants in the Cervical group decreased the percentage of time and the total amount of time they spent in provocative postures (p = .001). More specifically, there was an increase in the percentage of time spent in SSL (p = .009) and a reduction in the percentage of time spent in PSL (p = .006) and prone (p = .016). The percentage or total amount of time participants spent in supine did not change significantly. With regard to total time in other sleep postures, participants increased the amount of time they spent in SSL (p = .022) and decreased the amount of time in PSL (p = .004) and prone (p = .014) (Table 23).

Table 23. Cervical group comparison of Percentage and Total Time in each sleep posture at Baseline and 4 Weeks

	Baseline		4 Weeks		Paired T-Test	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Percentage Time						
Supine	31.8	15.3	31.6	21.2	0.03	.977
Supportive side lying	30.8	17.5	52.4	19.8	-3.18	.009
Provocative side lying	32.1	16.8	14.4	13.9	3.37	.006
Prone	5.4	6.8	1.6	4.6	2.84	.016
Supportive Combined	62.5	15.8	84.0	14.5	-4.50	.001
Provocative Combined	37.5	15.8	16.0	14.5	4.50	.001
Total Time (minutes)						
Supine	166.2	87.1	155.8	101.5	0.46	.655
Supportive side lying	156.2	86.5	267.8	121.5	-2.67	.022
Provocative side lying	165.8	88.6	69.8	65.8	3.57	.004
Prone	27.4	34.5	7.0	20.3	2.93	.014
Supportive Combined	322.5	88.3	423.5	103.8	-2.98	.012
Provocative Combined	193.2	84.5	79.8	67.8	4.75	.001

Changes in percentage of time spent in each sleep posture after the intervention period, approximated those percentages of time spent in each sleep posture by the Control group at baseline (Table 24).

Table 24. Percentage of time in Cervical and Lumbar groups at 4 weeks compared to Control group at Baseline

	Control	Cervical		Lumbar	
Variable	Baseline %	Baseline %	4 Weeks %	Baseline %	4 Weeks %
Supine	39	32	32	34	36
Supportive side lying	43	31	52	39	50
Provocative side lying	16	32	14	23	12
Prone	02	6	2	4	2
Supportive Combined	82	63	85	73	86
Provocative Combined	18	37	15	27	14

Following the postural education period there was a small, non-significant reduction in the number of posture shifts and while there were no significant changes in the standard or actual number of LPPI, participants spent significantly fewer actual LPPI in provocative sleep postures and more LPPI in supportive sleep postures (Table 25).

Table 25. Cervical group comparison of posture shifts and Long Periods of Postural Immobility at Baseline and 4 Weeks

	Baseline		4 Weeks		Paired T-Test	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Posture Shifts/night	24.29	6.30	21.04	7.46	1.36	.201
Standard definition # LPPI	6.00	0.67	5.67	1.44	0.77	.457
Actual # LPPI (every 30 minutes)	8.17	1.28	8.46	2.95	-0.38	.709
Actual # LPPI Periods in Supportive	5.33	1.83	7.75	3.33	-2.41	.035
Actual # LPPI Periods in Provocative	2.83	1.9	0.71	0.81	5.20	.002

Note. # LPPI = Number of long periods of postural immobility

5.2.1.2 Have the Prior 2 Weeks Waking Symptoms and Quality of Sleep Changed?

At each time-point, participants reported the severity of symptoms they experienced during the preceding 2 weeks using a NRS. The NRS scores for pain decreased following the intervention, recorded at 4 weeks, and continued to improve out to the 16 weeks follow-up (Table 26). A similar pattern was observed for stiffness and bothersomeness, however the reduction was not statistically significant for these variables (Table 26). Quality of sleep also improved after the intervention with further improvement apparent at 16 weeks (Table 26).

Table 26. Waking symptoms and quality of sleep in the Cervical group over the prior 2 weeks at three time points

	Baseline		4 weeks		16 weeks		ANOVA	
Prior 2 weeks	*M*	SD	*M*	*SD*	*M*	*SD*	*F*	*p*
Pain	4.64	1.56	2.82 [a]	2.52	2.54	3.1	4.12	.032
Stiffness	4.72	2.20	4.09	2.16	3.09	2.7	2.76	.088
Bothersomeness	5.27	1.90	4.18	2.36	3.64	2.69	2.20	.137
Quality of sleep	4.82	1.77	5.64	2.06	6.46 [a]	2.16	3.95	.036

Note. [a] significantly different from baseline

5.2.1.3 Have the Morning after the Video Waking Symptoms and Quality of Sleep Changed?

At time points where videos of sleep posture were recorded (Baseline and 4 weeks), participants were asked to record the severity of their symptoms and quality of sleep immediately in the morning on waking. There were significant improvements in the NRS for pain, stiffness and bothersomeness (Table 27). Interestingly while the quality of sleep improved, it was not significant (Table 27).

Table 27. Cervical group waking symptoms and quality of sleep on morning after videoing

	Baseline		4 Weeks		Paired T-Test	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Average morning pain	4.50	1.54	2.08	2.33	5.45	< .001
Average morning stiffness	5.12	1.30	2.83	2.41	4.75	.001
Average morning bothersomeness	5.08	1.30	2.96	2.12	4.78	.001
Average morning quality of sleep	5.71	1.75	5.96	2.08	-0.57	.583

5.2.1.4 Have Patient Reported Outcome Measures Changed?

At three time points, data for each PROs were collected from the Cervical group (Table 28). There were significant improvements in two pain and dysfunction PRO measures.

Table 28. Cervical group comparison of patient reported outcomes over 16 weeks

	Baseline		4 weeks		16 weeks		ANOVA	
	M	SD	*M*	*SD*	*M*	*SD*	*F*	*p*
NDI	18.18	10.06	13.45	9.51	1.82 [a, b]	2.27	21.76	<.001
SFI	80.55	14.59	83.46	16.80	91.45 [a, b]	9.80	6.54	.007
ISI	8.81	6.35	6.45	6.46	7.10	6.19	1.36	.278
PSQI	7.40	4.11	6.70	4.62	6.70	4.73	0.20	.823
SF36 PS	57.40	12.69	64.75 [a]	10.32	62.62	9.55	2.03	.178*
SF36 MS	76.10	11.05	72.80	9.64	77.06	9.61	0.99	.354*
HADS-A	5.27	2.80	4.81	2.89	4.55	3.39	0.36	.706
HADS-D	3.36	2.25	3.27	3.90	2.27	2.00	0.70	.509

Notes. NDI = Neck Disability Index, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, SF36 PS = Short Form 36 Physical Score, SF36 MS = Short Form 36 Mental Score, F = ANOVA statistic score, * Mauchly's test adjusted *p* value (Greenhouse-Geisser), [a] significantly different from baseline, [b] significantly different from 4 weeks

5.2.1.4.1 Pain and Disability

The 4 week sleep posture intervention elicited improvements in the NDI over time ($F(2, 20) = 21.578$, $p < .001$, partial η2= 0.685) (Table 28). There was a non-significant decrease in NDI from baseline to 4 weeks with a mean difference of -4.73 (95% CI: -9.64, .18) points ($p = .060$) and with improvement continuing from 4 weeks to 16 weeks with a mean difference of -11.64 (95% CI: -19.82, -3.45) points ($p = .007$), representing an overall improvement from baseline to 16 weeks of -16.36 (95% CI: -24.73, -8.00) points ($p = .001$).

There were also significant improvements in the SFI over time ($F(2, 20) = 6.54$, $p = .007$, partial η2= 0.40) (Table 28). The improvement in SFI achieved at the 4 week time point was not statistically significant with a mean difference of 2.91 (95% CI: -2.24, 8.06) percent, ($p = .236$), but with continued improvement from 4 weeks to 16 weeks the SFI was significant with a mean difference of 8.00 (95% CI: 0.12, 15.88) percent, ($p = .047$). There was a significant total improvement from baseline to 16 weeks of 10.91 (95% CI: 3.37, 18.45) percent ($p = .009$).

5.2.1.4.2 Insomnia and Quality of Sleep

The 4 week sleep posture intervention did not elicit significant improvements in the ISI, a clinical measure of insomnia over time ($F(2, 20) = 1.36$, $p = .278$, partial η2= 0.12) (Table 28).

The 4 week sleep posture intervention did not elicit significant improvements in the PSQI, a measure of sleep quality over time ($F(2, 20) = 0.22$, $p = .802$, partial η2= 0.02) (Table 28).

5.2.1.4.3 Quality of Life

The 4 week sleep posture intervention did not elicit significant improvements in the SF36 physical component over time ($F(2, 20) = 2.03$, $p = .178$, partial $\eta 2= 0.169$) (Table 28). Similarly, the intervention did not elicit any significant improvements in the SF36 mental component over time ($F(2, 20) = 0.99$, $p = .354$, partial $\eta 2= 0.09$) (Table 28).

5.2.1.4.4 Hospital Anxiety and Depression Scale

The 4 week sleep posture intervention did not elicit significant improvements in the anxiety subscale (HADS-A) over time, ($F(2, 20) = 0.36$, $p = .706$, partial $\eta 2= 0.03$) (Table 28). Similarly, there was no significant improvement in the depression subscale (HADS-D) over time, ($F(2, 20) = 0.70$, $p = .699$, partial $\eta 2= 0.06$) (Table 28).

5.2.2 Lumbar Group Comparisons

In this section the responses of the Lumbar group to the sleep posture education intervention will be reported.

5.2.2.1 Have the Video Characteristics of Sleep Posture Changed?

Following the postural education, participants in the Lumbar group decreased the percentage of time and the total amount of time they spent in provocative sleep postures ($p < .001$). More specifically, there was an increase in the percentage ($p = .003$) and amount of time ($p = .020$) spent in SSL and a reduction in the percentage ($p = .003$) and amount of time ($p = .001$) spent in PSL. While the mean amount of time and percentage of time spent in prone reduced, this was not significant and similarly while the percentage and amount of time participants spent in supine increased it was not significant (Table 29).

Table 29. Lumbar group comparison of Percentage and Total Time in each sleep posture at Baseline and 4 Weeks

	Baseline		4 Weeks		Paired T-Test	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Percentage Time						
Supine	33.99	17.18	35.97	16.86	-0.65	.524
Supportive side lying	37.71	15.83	50.10	19.48	-3.49	.003
Provocative side lying	24.16	19.08	12.18	18.25	3.49	.003
Prone	4.12	6.59	1.75	3.62	1.68	.111
Non-Provocative Combined	71.71	18.91	86.07	19.49	-4.23	< .001
Provocative Combined	28.29	18.91	13.93	19.49	4.23	< .001
Total Time (minutes)						
Supine	162.40	72.54	164.50	74.72	-0.13	.899
Supportive side lying	189.10	89.16	233.63	95.28	-2.56	.020
Provocative side lying	121.36	96.76	57.21	86.43	4.08	.001
Prone	20.26	32.48	8.40	19.70	1.66	.114
Non-Provocative Combined	351.47	98.45	398.13	94.91	-2.02	.059
Provocative Combined	141.63	95.66	65.60	21.28	4.95	< .001

Following the postural education period, participants in the Lumbar group decreased the number of posture changes and while there was no significant change in the standard definition or actual number of LPPI, participants spent significantly fewer actual LPPI in provocative sleep postures and more LPPI in supportive sleep postures (Table 30).

Table 30. Group comparison of posture shifts and Long Periods of Postural Immobility at Baseline and 4 Weeks

	Baseline		4 Weeks		Paired T Test	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Posture Shifts/night	23.42	9.03	18.92	6.91	2.76	.013
Standard definition # LPPI	5.90	1.5	5.87	1.26	0.07	.942
Actual # LPPI (every 30 minutes)	7.86	1.95	8.13	2.22	-0.51	.616
Actual # LPPI Periods in Non-Prov.	5.90	2.49	7.60	2.34	-3.62	.002
Actual # LPPI Periods in Prov.	1.97	1.84	0.71	1.35	3.29	.004

Notes. # = Number of, LPPI = Long periods of postural immobility

5.2.2.2 Have the Prior 2 Weeks Waking Symptoms and Quality of Sleep Changed?

At each time-point, participants reported the severity of symptoms they had experienced during the preceding 2 weeks using a NRS. The NRS scores for pain, stiffness and bothersomeness decreased following the education intervention recorded at 4 weeks and continued to improve out to the 16 weeks follow up (Table 31). Quality of sleep improved at each time point after the intervention (Table 31).

Table 31. Waking symptoms and quality of sleep in the Lumbar group over the prior 2 weeks at three time points

	Baseline		4 weeks		16 weeks		ANOVA	
Prior 2 weeks	*M*	SD	*M*	*SD*	*M*	*SD*	*F*	*p*
Pain	3.42	1.64	2.05 [a]	1.81	1.52 [a]	1.61	9.77	< .001
Stiffness	4.74	1.62	3.68 [a]	1.76	2.79 [a, b]	1.87	10.28	< .001
Bothersomeness	4.37	1.30	3.10 [a]	1.79	2.58 [a]	1.83	7.90	.001
Quality of sleep	4.74	2.05	5.63	1.77	6.84 [a, b]	1.77	10.67	< .001

Notes. [a] significantly different from baseline, [b] significantly different from 4 weeks

5.2.2.3 Have the Morning after the Video Waking Symptoms and Quality of Sleep Changed?

At time points where videos of sleep posture were recorded (Baseline and 4 weeks), participants were asked to record the severity of their symptoms and quality of sleep immediately in the morning on waking. There were significant improvements in the NRS for pain, stiffness and bothersomeness (Table 32). Interestingly, there was no significant improvement in quality of sleep (Table 32).

Table 32. Lumbar group waking symptoms on morning after videoing

	Baseline		4 Weeks		Paired T-Test	
Variable	*M*	*SD*	*M*	*SD*	*t*	*p*
Average morning pain	3.00	1.47	1.68	1.56	2.79	.012
Average morning stiffness	4.15	1.59	2.82	1.97	2.92	.009
Average morning bothersomeness	3.68	1.68	2.37	1.85	2.62	.018
Average morning quality of sleep	5.10	1.56	5.371	1.85	-1.77	.093

5.2.2.4 Have Patient Reported Outcome Measures Changed?

At three time points, data for each PROs were collected from the Lumbar group (Table 33). There were significant improvements in all PRO measures, other than the PSQI.

Table 33. Lumbar group comparison of patient reported outcomes over 16 weeks

	Baseline		4 weeks		16 weeks		ANOVA	
	M	SD	*M*	*SD*	*M*	*SD*	*F*	*p*
RMQ	2.79	2.25	0.90 [a]	1.70	0.90 [a]	1.37	10.42*	< .001
RMQ (2)	2.65	2.23	0.35 [a]	0.49	0.65 [a]	1.00	15.04*	.001
SFI	79.16	12.48	89.68 [a]	10.90	91.47 [a]	11.87	20.25	< .001
ISI	9.42	5.10	6.42 [a]	4.17	5.63 [a]	5.21	10.40	< .001
PSQI	6.74	3.10	5.84	2.83	5.05	3.66	3.56*	.055
SF36 PS	60.20	9.34	65.80 [a]	7.10	65.34 [a]	8.74	4.94	.013
SF36 MS	73.19	14.48	79.16 [a]	11.84	79.43 [a]	12.82	6.75*	.008
HADS-A	6.42	4.81	4.26 [a]	4.22	3.68 [a]	3.67	6.74*	.010
HADS-D	3.05	3.24	2.16	2.54	1.31 [a, b]	1.56	4.28*	.037

Notes. RMQ = Roland-Morris Disability Questionnaire, RMD (2) = results following removal of extreme outliers, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, SF36 PS = Short Form 36 Physical Score, SF36 MS = Short Form 36 Mental Score, F = ANOVA statistic score, * Mauchly's test adjusted *p* value (Greenhouse-Geisser), [a] significantly different from baseline, [b] significantly different from 4 weeks

5.2.2.4.1 Pain and Disability

The 4 week sleep posture intervention elicited improvements in the RMQ over time ($F(1.42, 25.69) = 10.42$, $p < .001$, partial η2 = 0.367) (Table 33). The RMQ decreased from baseline to 4 weeks with a mean difference of -1.90 (95% CI: -3.16, -0.63) points ($p = .006$) but not from 4 weeks to 16 weeks, mean difference of 0.00 (95% CI: -0.70, 0.70) points ($p = 1.00$). There was however a significant improvement from baseline to 16 weeks with an improvement in the mean difference of -1.895 (95% CI: -32.87 to -0.692) points ($p = .001$). A similar result was noted after removal of the two extreme outliers.

The intervention also elicited significant improvements in the SFI over time ($F(2, 36) = 20.246$, $p < .001$, partial η2= 0.529) (Table 33). The SFI improved from baseline to 4 weeks with a mean difference of 10.53 (95% CI: 5.22, 15.82) percent ($p = .001$) but not from 4 to 16 weeks, mean difference of 1.79 (95% CI: -1.37, 4.95) percent ($p = .250$). Overall there was a significant improvement from baseline to 16 weeks with a mean difference of 12.32 (95% CI: 7.86, 16.77) percent ($p < .001$).

5.2.2.4.2 Insomnia and Sleep Quality

The 4 week sleep posture intervention elicited improvements in the ISI over time ($F(2, 20) = 10.40$, $p < .001$, partial η2= 0.36) (Table 33). The ISI decreased from baseline to 4 weeks, mean difference of -3.0 (95% CI: -4.90, -1.15) points ($p = .003$) and continued to improve from 4 to 16 weeks, mean difference of -0.79 (95% CI: -2.52, 0.94) points ($p = .350$). Overall, there was a significant improvement from baseline to 16 weeks after intervention, mean difference of-3.79 (95% CI: -5.73, -1.85) points ($p = .001$).

The 4 week sleep posture intervention elicited a non-significant improvement in the PSQI over time ($F(1.49, 26.74) = 3.56$, $p = .055$, partial η2= 0.16) (Table 33).

5.2.2.4.3 Quality of Life

The 4 week sleep posture intervention elicited improvements in the SF36 PC over time ($F(2, 20) = 4.94$, $p = .013$, partial η2= 0.22) (Table 33). The SF36 PC improved from baseline to 4 weeks, mean difference of 5.60 (95% CI: 2.07, 9.13) points (p = .004). Improvements continued (non-significant) from 4 to 16 weeks after intervention, mean difference -0.46 (95% CI: -4.41 to 3.50) points (p = .812) and from baseline to 16 weeks post-intervention there was a significant improvement, mean difference of 5.14 (95% CI: 0.27, 10.02) points (p = .040).

Similarly, the 4 week sleep posture intervention elicited improvements in the SF36 MC over time ($F(2, 20) = 6.76$, $p = .008$, partial η2= 0.27) (Table 33). The SF36 MC increased from baseline to 4 weeks, mean difference of 5.96 (95% CI: 1.46, 10.47) points (p = .012) with a continued non-significant improvement from 4 to 16 weeks, mean difference = 0.27 (95% CI: -2.23 to 2.77) points (p = .823). From baseline to 16 weeks post-intervention, there was a significant mean difference improvement of 6.23 (95% CI: 1.53, 10.94) points (p = .012).

5.2.2.4.4 Hospital Anxiety and Depression Scale

The 4 week sleep posture intervention elicited improvements in the HADS-A over time (F(1.32, 23.84) = 6.75, p = .010, partial η2= 0.273) (Table 33). The HADS-A decreased from baseline to 4 weeks, mean difference of -2.16 (95% CI: -4.11, -0.21) points (p = .032). A non-significant decreased continued from 4 to 16 weeks, mean difference of -0.58 (95% CI: -1.46, 0.31) points (p = .186) and overall there was a significant decrease from baseline to 16 weeks, mean difference of -2.74 (95% CI: -4.63, -0.84) points (p = .007).

The 4 week sleep posture intervention elicited improvements in the HADS-D over time (F(1.40, 25.10) = 4.28, p = .037, partial η2= 0.19) (Table 33). The improvement in HADS-D at 4 weeks was not significant, mean difference of -0.90 (95% CI: -2.18, 0.39) points (p = .161). There was a significant improvement from 4 to 16 weeks, mean difference of -0.84 (95% CI: -1.63, -0.51) points (p = .038) resulting in a significant improvement from baseline to 16 weeks, mean difference of -1.74 (95% CI: -3.28, -0.19) points (p = .030).

5.2.3 Were Change Scores Clinically Relevant?

In comparing the change scores for each NRS between baseline and 16 weeks with published MCIDs, there were clinical improvements in both symptomatic groups for the NRS measures of pain, bothersomeness and quality of sleep. We could find no published MCID scores for stiffness, but stiffness improved more than the highest significant change score of 1.5 for pain and bothersomeness (Table 34). In addition to MCID changes, two NRS in the Cervical group and all NRS in the Lumbar group were statistically significant, see Table 26 for Cervical group and Table 31 for Lumbar group.

In comparing the change score for each PRO between baseline and 16 weeks after intervention, in the Cervical group there were clinical improvements in NDI, SFI and the SF36 physical component score. In the Lumbar group there were clinical improvements in the SFI, HADS-A, HADS-D and both the SF36 physical and mental component scores (Table 34). Most of the PROs that had MCIDs in the Lumbar group were also statistically significant over the 16 weeks, see Table 33 and NDI and SFI were significant in the Cervical group, see Table 31.

Table 34. Minimal Clinical Important Differences between Baseline and 16 Weeks

Variable	MCID	Cervical Group	Lumbar Group
Numerical Rating Scales			
Pain	Cervical 0.4 – 2.5, Lumbar 1.5	2.1*	1.90*
Stiffness	Unknown	1.63	1.95*
Bothersomeness	1.5	1.63	1.79*
Quality of sleep	0.6	1.64*	2.10*
Patient Reported Outcomes			
RMD	30%	Not applicable	32%*
NDI	3.5	8.64*	Not applicable
SFI	Cervical 1.7, Lumbar 1.5	2.72*	3.08*
ISI	6	1.71	3.79*
PSQI	3	0.7	1.69
SF36 PS	3.5	5.22	5.14*
SF36 MS	3.5	0.96	6.24*
HADS-A	1.5 or 20%	0.72	2.74*
HADS-D	1.5 or 20%	1.09	1.74*

Notes. RMD = Roland-Morris Disability Questionnaire, NDI = Neck Disability Index, HADS = Hospital Anxiety and Depression Scale, PSQI = Pittsburgh Sleep Quality Index, SF36 PS = Short Form 36 Physical Score, SF36 MS = Short Form 36 Mental Score, * statistically significant results transferred from Tables 26, 28, 31 and 33.

5.3 Chapter 5 Key Points

In a larger sample (N=53), self-report of sleep posture was found to be inaccurate for all key sleep postures

In comparison to the Control group at baseline;

- Participants in both symptomatic groups experienced increased waking symptoms and decreased sleep quality

- Participants in the Cervical group recorded higher pain and disability (e.g., NDI, SFI), poorer sleep (e.g., PSQI, ISI), poorer physical quality of life and poorer mental health (e.g., HADS-A, HADS-D)

- Participants in the Cervical group spent more time in provocative sleep postures, changed posture frequently and more long periods in provocative sleep postures

- Participants in the Lumbar group recorded higher pain and disability (e.g., RMQ, SFI), poorer sleep (e.g., PSQI, ISI), poorer quality of life (e.g., SF36 P, SF36M) and more anxiety (e.g., HADS-A)

- Participants in the Lumbar group spent more time in provocative sleep postures, changed posture frequently (non-significant) and more long periods in provocative sleep postures (non-significant)

In comparison to baseline data;

- 4 weeks later, participants in the Cervical group spent less time in provocative sleep postures, more time in supportive side lying and more long periods in supportive postures

- 16 weeks later, participants in the Cervical group reported a decrease in waking pain, an increase in waking quality of sleep and an improvement in pain and disability PRO (e.g., NDI, SFI)

- 4 weeks later, participants in the Lumbar group spent less time in provocative sleep postures, more time in supportive side lying, more long periods in supportive postures and less posture shifts

- 16 weeks later, participants in the Lumbar group reported a decrease in all waking symptoms and an improvement in all PROs, except PSQI

- A range of changes scores were both significant and MCID

In comparison to the Control group, both symptomatic groups after intervention spent approximately similar percentages of time in key sleep postures.

Chapter 6. Scoping Review

This chapter is adapted from a manuscript (Cary, Briffa, et al., 2019) titled, Identifying relationships between sleep posture and non-specific spinal symptoms in adults: A scoping review. See Appendix 22.

6.1 Introduction

Cervical and lumbar symptoms like pain, are the leading cause of musculoskeletal disability in most countries and most age groups (Hurwitz et al., 2018). The one-year prevalence in the general population for cervical pain ranges from 30 to 50% (Hogg-Johnson et al., 2008) and the one-year prevalence of lumbar pain in the adult population is reported as 38% (Hoy et al., 2012). Of those who report cervical and lumbar pain, the proportion is higher in females for both cervical (59%) (Côté, Cassidy, Carroll, & Kristman, 2004) and lumbar (52%) pain (Hoy et al., 2012). The prevalence of both cervical and lumbar pain has increased markedly over the past 25 years (cervical 21.1% and lumbar 17.3%), and these rates are expected to continue rising (Hurwitz et al., 2018). Cervical and lumbar pain contribute to large economic and societal costs and are major sources of work disability, being either the first or second ranked causes of years lived with disability between the ages of 20 and 79 years (Ekman et al., 2005; Hurwitz et al., 2018; Wasiak et al., 2006). Peak incidence of cervical pain occurs in middle aged groups of 35 to 44 years (Rekola, Keinänen-Kiukaanniemi, & Takala, 1993) and 40 to 49 years (Bot et al., 2005), whereas the highest incidence of lumbar pain is reported between the ages of 46 to 64 years (Hoy et al., 2012; Kopec, Sayre, & Esdaile, 2004). Research indicates that remissions in symptoms are temporary rather than permanent (Croft et al., 2001; Hestbaek et al., 2006) and cervical and lumbar pain becomes chronic in 25 to 60% of cases (Manchikanti et al., 2009). Other types of symptoms like stiffness and bothersomeness, are less well investigated, but are still important, as discussed in Section 2.5.1. Identification of modifiable risk factors contributing to the onset and chronicity of cervical and lumbar pain and other symptoms, is critical (Croft, Dunn, & Raspe, 2006) to improve the management of cervical and lumbar pain.

A potentially modifiable risk factor that aggravates spinal symptoms, is sleep posture. Sleep is considered essential for human mental and physical recovery, yet every night some people go to bed, only to wake with spinal symptoms not present the prior evening. It has been postulated that poor sleep posture may be a factor in the development of both waking cervical (Corrigan & March, 1984; Gordon et al., 2002) and lumbar symptoms (Desouzart et al., 2016; Gracovetsky, 1987). There is a general agreement in the bidirectional relationship between sleep and pain, however, it is becoming increasingly clear that changes in sleep complaints, are a stronger predictor of pain, than changes in pain, are a predictor of sleep complaints (Koffel et al., 2016).

Habitual sleep postures may influence the amount of load applied to spinal tissues when sleeping. The magnitude of load experienced when sleeping at night is likely to be far less than during the day. During the day, in upright and recumbent postures, loads imposed on spinal structures include compression, elongation and shear, as discussed in Section 2.3.1. In a 25 year review on the fundamentals of spinal biomechanics, it was noted that spinal movements decreased under a superimposed compression load. The author postulated this was due to increased anular stiffness and increased ZPJ contact (Oxland, 2016). Conversely, when lying down and sleeping, the sources of spinal compression are minimal, creating a low compression environment, potentially allowing an increased range of spinal movement.

Sleep involves both sustained and repeated postures. Sustained sleep posture habits have been investigated by prior authors, who reported that adults on average changed their posture between 2.1 and 3.6 times per hour (De Koninck et al., 1992). This indicates that sleep postures are commonly sustained for periods of greater than 15 minutes, a time frame in which in vitro viscoelastic collagenous tissue creep has been demonstrated (Yahia et al., 1991). Viscoelastic tissues are vulnerable to sustained or repeated low elongation loads, and undergo predictable mechanical and viscoelastic changes, like creep, hysteresis and fatigue failure, as discussed in Section 2.3.2.3. Sleep postures that are not symmetrical if sustained and unsupported, have been shown to result in structural spinal changes (Hill & Goldsmith, 2010; Waugh & Hill, 2009) and associations have been identified between biomechanical creep and spinal symptoms, as a result of micro-damage to viscoelastic tissues (Solomonow, Baratta, et al., 2003) have been discussed in Section 2.4.

Some sleep postures, such as prone, are clinically believed to increase load on spinal tissues, reducing recovery and provoking waking spinal symptoms (De Koninck et al., 1992; Goldman, 2005; Gracovetsky, 1987). Sleep postures have been shown to be modifiable (Desouzart et al., 2016; Murayama et al., 2011) and identification of modifiable risk factors related to spinal pain, have been highlighted as a priority in managing disabling lumbar pain (Buchbinder et al., 2018). While some sleep research has examined the role sleep posture may have on waking spinal symptoms (Desouzart, Filgueiras, et al., 2014; Desouzart et al., 2016; Gordon et al., 2007a), there has been no synthesis of the literature in regard to sleep posture and spinal symptoms. A synthesis of the prior research may be difficult for clinicians, as the relevant information is found in diverse disciplines of research, sleep, ergonomics, biomechanics, information technology and therapeutics, and clinicians may not have access to all these sources. The purpose of this scoping review was therefore to establish the body of evidence, regarding relationships between sleeping posture and spinal symptoms and to provide suggestions as to what sleeping postures can be recommended by clinicians, to assist those with or experiencing exacerbations of spinal symptoms.

6.2 Methods

6.2.1 Search Framework

This scoping review was developed using the methodological framework proposed by previous authors (Arksey & O'Malley, 2005), further refined by other independent authors and institutes (Khalil et al., 2016; Levac, Colquhoun, & O'Brien, 2010; Peters et al., 2015) and reported in line with key Preferred Reporting Items for Systematic Reviews and Meta-Analyses for scoping reviews (PRISMA) guidelines.(Tricco et al., 2018). This method was used as it provided a structured framework, ensuring a stringent assessment of available articles. It followed five stages:

1) Identify the research question, aims and objectives.
2) Identify the relevant articles.
3) Study selection.
4) Present the data.
5) Collate and summarise the results.

6.2.2 The Research Question

Following an individual review of the literature and a group meeting between the principal investigators, a consensus was reached to determine the following research question; is there a relationship between sleep posture and spinal symptoms?

6.2.3 Aim and Objectives

The aim of this scoping review was to gain a clear understanding of the current knowledge base in relation to the identified research question. To achieve this aim, an iterative process involving electronic meetings and communications between authors was used to determine the following research objectives:

1) Identify what study designs and participant populations have been studied to answer the research question.
2) Identify the types of specific methodology used in the body of evidence to address the research question.
3) Identify common results, conclusions and recommendations from the body of evidence regarding the research question.

6.2.4 Eligibility Criteria

Eligibility criteria were based upon the population, intervention, comparison and outcome (PICO) framework. A draft list of eligibility criteria was initially determined following the independent screening of relevant articles by two reviewers. Criteria were then developed iteratively between two reviewers and a finalised list of criteria were uploaded to Covidence (2018), as a reference for data charting reviewers.

6.2.4.1 Inclusion Criteria

For inclusion in this scoping review, the prior research needed to study participants 18 years or older, with either pain, stiffness or bothersomeness in the cervical, thoracic or lumbar spine. Any observational or interventional study examining the relationship between sleep posture and spinal symptoms was considered. Articles that either compared sleep posture change (e.g., before and after an intervention) or had no comparator (e.g., epidemiological) were included. Articles needed to use a subjective or objective measure for both symptoms (e.g., pain, stiffness or bothersomeness) and sleeping posture. All research designs were initially considered.

6.2.4.2 Exclusion Criteria

Articles were excluded if they involved animals, cadavers or included participants diagnosed with sleep apnoea, spinal stenosis, migraine, red flag pathologies (e.g., neoplasm, inflammatory conditions, fractures or infections); participants with pain of known non-spinal origin (e.g., kidney disease, post-operative pain, temporomandibular joint, shoulder pain); participants with neurological conditions (e.g., multiple sclerosis, cerebrovascular accident); or participants that were unable to move freely in bed (e.g., using continuous positive airway pressure therapy or in the last trimester of pregnancy). Articles were excluded if they did not isolate the intervention when a group of interventions were implemented (e.g., spinal injection and sleeping posture) or if they compared sleep systems (e.g., mattress, base and or pillow) or changes in sleep systems but did not report the change in sleep posture. Further, articles using actigraphy to measure movement or articles that only examined the quality or efficacy of sleep were excluded. Finally, editorials, opinion-based articles, review articles (systematic or narrative) and articles not written in English were excluded.

6.2.5 Patient and Public involvement

Patients and the public were not involved in this scoping review.

6.2.6 Search Terms and Strategy

The PICO framework was used to generate a comprehensive list of key search terms to assist in the identification of all elements relevant to clinical research questions. Identified key search terms were then used in the search strategy to identify all relevant articles (Aromataris & Riitano, 2014; Portney & Watkins, 2009).

Population: Terms used for the search strategy were chosen to be representative of the areas and symptoms, likely to be experienced by a population with non-specific waking spinal symptoms. Non-specific symptoms are those not related to fracture, infection, inflammatory disease, tumor or spinal stenosis. **Intervention**: Terms representative of interventions aimed at changing sleep posture in association with waking spinal symptoms were considered for inclusion, while other terms not associated with waking spinal symptoms, for example apnoea were excluded. **Comparison**: Terms were considered that were indicative of any type of comparison. **Outcome**. Any terms to indicate the subjective measure of pain, stiffness or bothersomeness or objective measure used to evaluate sleep posture were considered.

Key terms that matched the PICO framework, were determined after several stages of trial searches and cross checking between the principal investigators. An interim list of keywords was established at this point.

Searching for relevant articles followed a three-step process:

1) An initial search to identify relevance of identified key and alternative terms.

2) A comprehensive search of relevant databases and grey literature.

3) A hand search of key articles and authors (Aromataris & Riitano, 2014).

Identified key search terms were then used in the search strategy to identify all relevant articles. An initial search was conducted in two of the four databases, recommended (Michaleff et al., 2011) for physiotherapy related topics; PEDro, and Embase (via Ovid) from inception to December 2017. The initial search was used to determine if the search terms and strategy were appropriate, and informed the development of the final search terms and strategy. The final search strategy was conducted using the search terms and Boolean logic. Table 35 describes one search strategy that was adapted for eight electronic databases (PEDro, Embase, Cumulative Index to Nursing and Allied Health Literature, Cochrane Library, Medline, ProQuest, PsycINFO, SportDISCUS) with the assistance of a health sciences information specialist. Grey literature (espace, Google Scholar (top 100 references scanned for relevance), and Web of Science) was searched for difficult to locate or unpublished material that had not already been included. The final step involved manual searching the reference sections of relevant articles and publications by key authors for additional articles, not identified in the original search.

Table 35. Search strategy for the Scopus database

Date	7/4/2018	
Strategy	#1 AND #2 AND #3 NOT #4	
Rule	Domain	Search Terms
#1	Area of symptoms	lumbar or "low back pain" or cervical or "neck pain" or "musculoskeletal pain" or "spinal pain"
#2	Posture	postur* or position* or prone or supine or lateral or side lying
#3	Sleep	sleep* or slumber* or night-time or nocturnal or bed
#4	Exclusions	apnoea or apnea or CPAP

6.2.7 Study Selection

All search results were imported into the reference management software package, Endnote X8 (EndNote, 2018) and duplicates removed. Remaining results were imported into Covidence (Covidence, 2018) and additional duplicates removed. Using Covidence, two reviewers independently performed level 1 (title and abstract) and level 2 (full text) screening, based on the eligibility criteria. Differences of opinion in which articles progressed to the next level, were first resolved with discussion between reviewers and if necessary, with input from a third reviewer. Excluded articles are detailed in Appendix 20.

6.2.8 Data Charting

The data charting form (see Appendix 21) was developed and revised iteratively between reviewers to ensure data relevant to the three research objectives were collected. A definitions and instructions document was developed to ensure that data was collected consistently by the independent reviewers. The data charting form was then independently pilot tested in duplicate on a random sample of four potential articles. Following identification of articles for inclusion in this review, data were independently charted in duplicate using a data charting form created in Excel and based upon the three research objectives:

1) For the first objective, first author and year of publication, study design, population type, sample size, gender and age were charted.

2) For the second objective, sleep environment, use of standard sleep posture definitions, number of sleep postures, sleep posture outcome measurement type, anatomical area of symptoms, symptom type, symptom characteristics and method of measuring waking symptoms were charted.

3) For the final objective, results, conclusions, recommendations and author

reported limitations were charted.

An attempt was made to contact authors of eligible articles, where authors reported that data relevant to our scoping review had been collected, but was not publicly available and to clarify specific points relevant to our data charting.

6.2.9 Quality of Evidence

Non-assessment of methodological quality and the risk of bias is consistent with current guidelines on conducting a scoping review (Khalil et al., 2016; Peters et al., 2015). However, a focus of this scoping review was on methodology. It was therefore decided in the early planning stages to include a methodological assessment of quality. The Downs and Black checklist is one of two identified checklists, for the appraisal of randomised and non-randomised studies in the Cochrane Handbook (Reeves, Deeks, Higgins, & Wells, 2008). Few critical appraisal tools have documented evidence of validity and reliability, but the Downs and Black checklist has documented criterion validity, face and content validity, intra-rater (r = .88) and inter-rater reliability (r = .75) and guidelines for use (Olivo et al., 2008). Validity of the other recommended checklist has been questioned (Stang, 2010). The Downs and Black checklist contains 27 questions distributed over five domains; reporting (aims, sampling and methods); external validity (generalisability); internal validity (study design, selection bias, performance and reporting bias); confounding; and power (Downs & Black, 1998). We utilised a modified version of the Downs and Black checklist (Korakakis, Whiteley, Tzavara, & Malliaropoulos, 2018) in which the score range for Question 27 (relating to power calculation) was changed from zero to five, to a score range from zero (unable to determine/not performed) to one (power calculation reported). As a result, the maximum score for randomised trials was 28 and non-randomised trials was 25. Using the Downs and Black checklist as the appraisal tool, evidence levels have previously been categorised as strong (> 75%), moderate (50 - 74%), limited (25 – 49%) and poor quality (< 24%) (Hignett, 2003). The Downs and Black checklist was independently completed for each article in duplicate. Differences in scoring were first resolved by consensus between reviewers and if required, by a third independent reviewer. Study limitations noted by authors were collected to compliment the Downs and Black checklist.

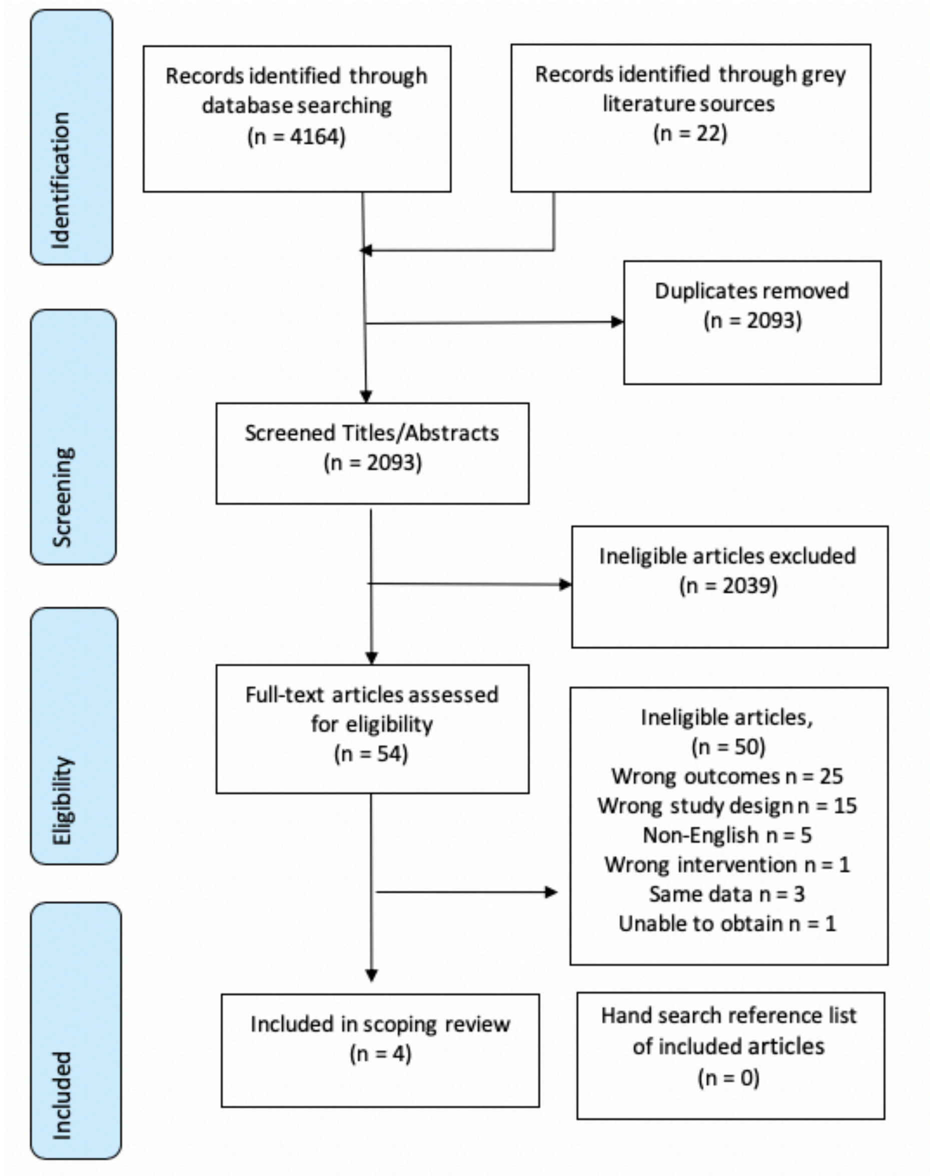

Figure 30. PRISMA flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses

6.3 Results

6.3.1 Search Results

An overview of the article identification process is provided in the PRISMA flow diagram given in Figure 30. Articles excluded due to wrong outcomes, were those that did not include a measure of sleep posture or only examined sleep posture and not symptoms, tested a sleeping system (e.g., mattress or pillow) in relation to spinal symptoms but not posture, or studied sleep posture in relation to sleep quality. Articles excluded due to wrong study design included treatment guidelines, opinion and editorial piece and summaries. Four articles were included for data charting.

Authors of included studies clarified the following aspects of their research:

- Duration of intervention period (Abanobi et al., 2015).
- Sleep questionnaire details (Cary et al., 2016).
- Use of pain VAS in association with sleep posture (Desouzart, 2018).
- Mean and standard deviation values of participants (Gordon, 2018).

6.3.2 Study Design and Population Characteristics

Characteristics of the included four studies are described in Table 36. One study was reported as interventional (Desouzart et al., 2016). The other three studies were exploratory in nature and used a mix of study designs including case controlled (Abanobi et al., 2015), cross sectional (Cary et al., 2016) and epidemiological (Gordon et al., 2007a). Across the included studies in which data was available, the mean percentage of female participants was 61% and the mean participant age was 47 years.

Table 36. Study design and population characteristics

Author	Study Design	Population type	Sample Size (Gender)	Age *M* (*SD*)
Abanobi et al., 2015	Epidemiological: case controlled	Welders in Owerri, Nigeria	100 (male = 100)	35 (9)
Cary et al., 2016	Epidemiological: cross sectional	Population of convenience in Esperance, Western Australia	15 (male = 7)	44 (17)
Desouzart et al., 2016	Controlled pilot	Elderly participants in physical activity program at Polytechnic Institute of Leiria, Portugal	20 (male = 0)	62 (4)
Gordon, Grimmer and Trott, 2007	Epidemiological: cross sectional	Every third household in Port Lincoln in South Australia	812 (male = 261)	Female 61 (10) Male 59 (11)

Notes. *M* = Mean, *SD* = Standard deviation

6.3.3 Methodology: Sleep Posture Measurement

All studies examined participants in their domestic environment (Table 37) and described as a minimum the three common sleep postures; supine, side lying and prone. One study described four sleep postures, dividing side lying into two sleep postures and named them supportive side lying and ¾ side lying (Cary et al., 2016). Another described five postures, adding “upright” and “varies”, to the common three sleep postures (Gordon et al., 2007a, p. 7). One study used three different postures, but combined side lying and prone for analysis, due to small number of prone sleepers, of whom none reported lumbar pain (Abanobi et al., 2015). All studies used self-report questionnaires to assess sleep posture. Studies focused on different time points when questioning about sleep posture.

Table 37. Mapping of sleep posture measurement

Author	Sleep environment	Standard three sleep postures	Number of sleep postures	Sleep posture outcome measurement
Abanobi et al., 2015	Domestic	Y	3	SR
Cary et al., 2016	Domestic	Y	4	SR + Video recording
Desouzart et al., 2016	Domestic	Y	3	SR
Gordon, Grimmer and Trott, 2007	Domestic	Y	5	SR

Notes. NS = Not stated, Y = Yes, SR = Self-report

Two specifically focused on night and waking posture; “in what sleep posture do you usually go to sleep”, “in what sleep posture do you usually wake up” and “in what sleep posture do you spend most of the night” (Gordon et al., 2007a, p. 7), and “which posture most closely resembles the posture you are lying in when you fall asleep?” and “which posture most closely resembles the posture you are lying in when you wake up?”(Cary et al., 2016) (Appendix 7).

The other two studies were non-specific, “usual sleep posture” (Abanobi et al., 2015, p. 335) and “informal questionnaire for ... sleeping position” (Desouzart et al., 2016, p. 237). In addition to using self-report, the authors of one study used an objective method of assessment, twin camera infrared video recording, to verify sleep posture (Cary et al., 2016).

6.3.4 Methodology: Measurement of Symptoms

The location of spinal symptoms measured, varied by anatomical area as presented in Table 38. One study included the classification ‘Other,’ to include non-spinal sources of symptoms (e.g., hip and legs) (Cary et al., 2016). All studies examined pain (with two studies examining additional symptoms), but differed in regard to examining intensity, frequency, period of symptoms and diurnal/nocturnal presence. In one study, participants answered a “question on LBP history, such as present and past low back history” (Abanobi et al., 2015, p. 333) and another asked participants “the frequency and location of morning symptoms of spine pain and stiffness that occurred during the past month” (Cary et al., 2016, p. 2). In the other two studies, one described the frequency and duration of morning pain and stiffness over the prior week, but not intensity (Gordon et al., 2007a) while the other used a VAS to measure pain intensity “at moment of response” but not frequency or duration (Desouzart et al., 2016, p. 237).

Table 38. Mapping of measurement of symptoms

Author	Anatomical Area	Symptom type	Symptom(s) characteristics	Symptom outcome measurement
Abanobi et al., 2015	Lumbar	Pain	Past and present history	Questionnaire - face to face interview
Cary et al., 2016	Cervical, Lumbar, Both, Other	Pain, Stiffness	Frequency (month) Waking symptoms	Questionnaire written
Desouzart et al., 2016	All spine	Pain	Intensity	Questionnaire written - pain VAS
Gordon, Grimmer and Trott, 2007	Cervical	Pain, Stiffness, HA, Shoulder blade/arm pain	Frequency (week), duration Waking symptoms	Questionnaire - structured telephone interview

Notes. HA = Headache, VAS = Visual analogue scale

6.3.5 Methodology: Interventions and Follow-ups

One of the four studies was an intervention (Desouzart et al., 2016). Only participants in the treatment group of the intervention study (Desouzart et al., 2016) received sleep posture education. Those with dorsal or lumbar symptoms were advised to sleep supine, those with cervical symptoms were advised to sleep in side lying and prone sleepers were advised to adopt either of the prior recommended sleep postures. Participants were also educated about the use of pillows and how to get up and lie down. The control group received no instruction and neither group received further contact until reassessment. The intervention phase lasted 4 weeks. A significant reduction in pain was reported in the treatment group but not the control group. However, sleep posture was not objectively confirmed at baseline or after the intervention period

6.3.6 Results, Conclusions and Recommendations

Results from all studies reported trends or significant associations between spinal pain and certain sleep postures (Table 39). The authors from three studies reported increased symptoms, one associated with supine (Abanobi et al., 2015) one upright (Gordon et al., 2007a) and the other prone or ¾ side lying (Cary et al., 2016) sleep postures. The authors from two studies reported significantly decreased symptoms, one with side lying (Gordon et al., 2007a) and the other a combination of side lying and supine (Desouzart et al., 2016). In the intervention study, baseline pain VAS was higher in the intervention group ($M = 5.40$, $SD = 2.01$) compared to the control group ($M = 4.30$, $SD = 2.36$). After the intervention phase there was a significant reduction in pain VAS ($M = 3.00$, $SD = 1.63$, $p = .009$). There was a non-significant change in the control group pain VAS ($M = 3.90$, $SD = 3.21$, $p = .472$) (Desouzart et al., 2016). Between groups comparisons were not reported, possibly because it was a pilot study. We used an online calculator (Centre for Evaluation and Monitoring, 2018) to determine an effect size with 95% CIs between groups, using baseline to post-intervention data in two steps. Baseline to post-intervention change was used because a significant difference between groups existed at baseline. First, a pooled SD for each group was calculated for change from baseline to final measure. Then this pooled SD from each group was used to calculate the between group effect size and 95% CI (Table 39). The resultant CI indicates that significant differences between groups were unlikely. To calculate an effect size for (Cary et al., 2016) the independent samples Jonckheere-Terpstra test (IBM Corporation, 2018) was used to calculate a z-score, which was then converted into an effect size (rj) (Field, 2017).

Conclusions from authors of all four studies, were that certain sleep posture could either increase or decrease spinal pain, and that addressing sleep posture could reduce the development of spinal pain. Using self-report, side lying was found in two studies, to be protective of spinal symptoms (Desouzart et al., 2016; Gordon et al., 2007a) and participants that slept in supported side lying were found to have less symptoms than those sleeping in ¾ side lying or prone (Cary et al., 2016). In one study it was recommended that participants do not sleep in prone (Desouzart et al., 2016), however prone was not significantly related to cervical symptoms (Gordon et al., 2007a) nor lumbar symptoms (Abanobi et al., 2015). Due to a small sample size, the authors recommended caution when interpreting their findings (Gordon et al., 2007a). In regard to supine, one study found supine increased the likelihood of lumbar pain by 1.9 times (Abanobi et al., 2015), another study recommended supine in combination with side lying sleep postures to reduce lumbar pain (Desouzart et al., 2016) and a third reported supine was not significantly protective of cervical waking symptoms (Gordon et al., 2007a). These variations in recommendations demonstrate the importance to consider relationships between anatomical areas and spinal symptoms, and objectively determining sleep posture and spinal symptoms. Two studies recommended clinicians consider sleep posture as part of the examination process in regard to reducing cervical (Gordon et al., 2007a) and lumbar symptoms (Desouzart et al., 2016).

Table 39. Mapping of results, conclusions and recommendations

Author	Results	Conclusions	Recommendations
Abanobi et al., 2015	ORs for LBP were in relation to a combined group of prone and side lying sleeping. “Sleeping with back (face up) increases the risk of developing low back pain by 1.9 times.” (p. 355) (95% CI 0.43 to 8.56)^	“The result showed the possibility of reducing the burden of LBP by appropriate training and improvement in habits such as...bad sleeping postures.” (p. 336)	Not provided
Cary et al., 2016	“The time spent in each of the sleeping postures ... expressed as a percentage of the time spent asleep, did not differ significantly according to the level of morning symptoms” (p. 5) Independent Samples Jonckheere-Terpstra Test; supine, rj=0.03; SSL, rj=0.00; ¾ SL, rj=0.34; prone, rj=0.31.	“participants that spent greater periods of time in SSL, had less mornings of symptoms per month than those that slept in ¾ SL or prone.” (p. 5)	Not provided
Desouzart et al., 2016	No between group comparison reported. Between group effect size calculated to be 0.81 (95% CI −0.11 to 1.72).	“It may be concluded that the indication of the ideal way to lie down, which corresponds to a recommended sleeping posture with the ideal position to place the pillows, as well as the ideal way to get up.” (p. 239)	Ideal sleep posture, pillow use and way to get up, as per experimental group, “is an added value for the prevention and decrease of the pain and/or discomfort in the spine in active seniors.” (p. 239)
Gordon, Grimmer and Trott, 2007a	“Subjects who reported sleeping mostly in an upright position were significantly more likely to report all waking symptoms of interest compared with subjects who slept in other positions.” (p. 6) Waking cervical pain OR 2.5 (95% CI 1.1 to 5.5), cervical stiffness OR 2.6 (95% CI 1.1 to 5.8), headache OR 2.2 (95% CI 1.0 to 5.0), scapular/arm pain OR 2.5 (95% CI 1.1 to 5.3). “Supine…was not found in this study to be significantly protective of waking symptoms, when compared with other sleep positions.” (p. 6) Waking cervical pain OR 1.4 (95% CI 0.8 to 2.5) and cervical stiffness OR 0.9 (95% CI 0.5 to 1.6). “Prone…was not significantly associated with waking symptom” (p. 6). Cervical pain OR 1.5 (95% CI 0.7 to 3.2) and cervical stiffness OR 1.1 (95% CI 0.5 to 2.6).		“on the basis of this research SL can be confidently recommended as the best sleep position in terms of minimising waking symptoms.” (p. 6) “need for health professionals to consider individual’s sleep position and waking symptom history, as part of clinical reasoning for treatment, and when developing a management plan for

"Subjects who reported that they slept mostly on their side were significantly less likely to report waking cervical pain… compared with subjects who slept in any other position." (p. 4) Waking cervical pain OR 0.6 (95% CI 0.4 to 0.9) and scapular/arm pain OR 0.7 (95% CI 0.5 to 0.9).	patients with troublesome waking symptoms." (p. 6)

Notes. *The CI was recalculated as it was suspected wrong due a typographical error. The original value was 0.431. ¾ SL = ¾ side lying; rj = effect size r for Jonckheere-Terpstra test. LBP = low back pain; SSL = supported side lying; VAS = Visual Analogue Scale

6.3.7 Quality of Evidence and Author Reported Limitations

The Downs and Black checklist contains 27 questions distributed over five domains; reporting (i.e., aims, sampling and methods); external validity (i.e., generalisability); internal validity (i.e., study design, selection bias, performance and reporting bias); confounding and power (Downs & Black, 1998). Using the Downs and Black checklist as the appraisal tool, evidence levels have previously been categorised as strong (>75%), moderate (50% to 74%), limited (25% to 49%) and poor quality (<24%) (Hignett, 2003). Questions 4, 8, 9, 13, 14, 15, 19, 23, 24 and 26 (Table 40) were not applicable to study designs that did not include an intervention group and were therefore excluded from the three epidemiological studies (Abanobi et al., 2015; Cary et al., 2016; Gordon et al., 2007a). Question 27 was applicable for all but the cross-sectional study (Cary et al., 2016). In the reporting subsection, questions 1 to10, studies were well documented with one different applicable question not completed by each study, enabling readers to draw unbiased assessments of each study's findings. Questions 11to 13 (external validity) were poorly reported, with all studies failing to quantify the proportion of participants that were asked, relative to the proportion of participants that were accepted into studies. All studies reported using either random (Abanobi et al., 2015; Desouzart et al., 2016; Gordon et al., 2007a) or consecutive sampling (Cary et al., 2016). Internal validity, questions 14 to 20, examined measurement bias and apart from question 15 were well documented. In all studies, no attempt was made to blind researchers measuring the outcome variables. However, in one epidemiological study, the interview method precluded the need for blinding of interviewers (Gordon et al., 2007a). All the remaining were well documented, except for question 25 which examined confounding factors. This was poorly documented except for one study (Gordon et al., 2007a) in which a multivariate analysis was reported in a subsequent study, using the same data. The body of evidence in this scoping review is rated as moderate to strong quality.

Table 40. Critical appraisal of included studies using the Downs and Black checklist

Section	Questions		Abanobi et al., 2015	Cary et al., 2016	Desouzart et al., 2016	Gordon, Grimmer and Trott, 2007
Reporting	1	Is the hypothesis/aim/objective of the study clearly described?	Y	Y	Y	Y
	2	Are the main outcomes to be measured clearly described in the Introduction or Methods section?	N	Y	Y	Y
	3	Are the characteristics of the patients included in the study clearly described?	Y	N	Y	X
	4	Are the interventions of interest clearly described?	X	X	Y	X
	5	Are the distributions of principal confounders in each group of subjects to be compared clearly described?	*Y	X	*Y	*Y
	6	Are the main findings of the study clearly described?	Y	Y	Y	Y
	7	Does the study provide estimates of the random variability in the data for the main outcomes?	Y	Y	Y	Y
	8	Have all important adverse events that may be a consequence of the intervention been reported?	X	X	N	X
	9	Have the characteristics of patients lost to follow-up been described?	X	X	Y	X
	10	Have actual probability values been reported (e.g., 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?	Y	Y	Y	N
External Validity	11	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	Y	Y	N	Y
	12	Were those subjects who were prepared to participate representative of the entire	U	N	N	N

		population from which they were recruited?				
	13	Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?	X	X	Y	X
Internal Validity: Bias	14	Was an attempt made to blind study subjects to the intervention they have received?	X	X	U	X
	15	Was an attempt made to blind those measuring the main outcomes of the intervention?	X	X	N	X
	16	If any of the results of the study were based on "data dredging", was this made clear?	Y	Y	Y	Y
	17	In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?	Y	X	Y	X
	18	Were the statistical tests used to assess the main outcomes appropriate?	Y	Y	Y	Y
	19	Was compliance with the intervention/s reliable?	X	X	U	X
	20	Were the main outcome measures used accurate (valid and reliable)?	Y	Y	Y	Y
Internal Validity: Confounding	21	Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?	Y	X	Y	Y
	22	Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?	Y	X	Y	X
	23	Were study subjects randomised to intervention groups?	X	X	Y	X
	24	Was the randomised intervention assignment concealed from both patients	X	X	U	X

		and health care staff until recruitment was complete and irrevocable?				
	25	Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	N	N	N	Y
	26	Were losses of patients to follow-up taken into account?	X	X	Y	X
Power	27	Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?	N	X	N	N
Score			14/17	9/12	19/28	12/14
Percentage			82	75	68	86

Notes. N = No = 0, Y = Yes = 1, *Y = 2 points, U = Unable to determine = 0, X = Not applicable (See Section 6.4.7.)

Evidence levels = strong (>75%), moderate (50% to74%), limited (25% to 49%) and poor quality (<24%) (Hignett, 2003).

Authors identified reliance on self-report to examine sleep posture (Desouzart et al., 2016) and symptoms (Gordon et al., 2007a) as a limitation (Table 41). Authors identified small sample sizes, as limiting their ability to draw firm conclusions from the obtained results (Desouzart et al., 2016; Gordon et al., 2007a). Authors identified restricted time as a limitation, for the period available for data collection (Abanobi et al., 2015), and for participants to learn a new sleeping habit (Desouzart et al., 2016).

Table 41. Author reported limitations

Author	Comments
Abanobi et al., 2015	"Inability to compare the effect of duration of habits and age at onset of habit" (p. 336)
	"Limited time set aside for the surveillance exercise" (p. 336)
Cary et al., 2016	"Mismatch in time frame of measurement" (p. 6). Recording of sleep posture occurred over 2 nights but participants questioned about symptoms over prior 1 month.
Desouzart et al., 2016	Due to the population studied it was "not possible to use a homogenous sample and larger number of participants." (p. 239)
	"The four weeks may not have been sufficient to create habits in participants, however, and because of the time limitations of this study, it was not possible to have a longer time." (p. 239)
	"results are based on the statements of the participants" (p. 239)
Gordon, Grimmer and Trott, 2007	"As small subject numbers constrained confidence in the findings, further research is required into the contributors to waking symptoms. for upright sleepers" (p. 6)

6.4 Discussion

To our knowledge, this scoping review is the first to establish the body of evidence regarding the research question; relationships between sleeping posture and spinal symptoms. Generally, there was limited available research. In regard to objective 1; research designs and populations studied for the research question, a variety of study designs, participant populations and sample sizes were used. One study was a controlled pilot trial. With regard to objective 2; methods used to address the research question, sleep was assessed in a domestic environment in all studies, with self-report used to measure sleep posture in all studies. Pain was the most common outcome measure of symptoms. In respect to objective 3; common conclusions regarding the research question, most authors recommended side lying as the sleep posture least likely to provoke spinal symptoms, be they cervical or lumbar. Studies included in this scoping review were of moderate to strong quality as assessed using the Downs and Black critical appraisal tool. Nonetheless, considerably more research including longitudinal studies, is require before causal relationship between sleep posture and spinal symptoms could be concluded.

6.4.1 Study Designs and Population Characteristics

The study designs identified in this scoping review were appropriate to use for the research question (Table 36). The use of observational study designs assisted in the identification of relationships between different sleep postures and spinal symptoms. The single intervention study, reported that modification to self-reported sleep posture changed spinal pain. The variety of study designs prevented data pooling and a scoping review remained the most appropriate approach to synthesise the research.

The gender ratios of included studies were not representative of typical cervical and lumbar pain populations (Côté et al., 2004; Hoy et al., 2012; Hurwitz et al., 2018). Two studies included participants of mixed gender with a higher percentages of female participants (Cary et al., 2016; Gordon et al., 2007a), which is appropriately representative of female proportions reported in cervical and lumbar pain populations, however, two studies had highly specific populations; one study solely containing male participants (Abanobi et al., 2015) and another only female participants (Desouzart et al., 2016). The mean age of participants in this scoping review was 58 years, which is similar to the mean age of people in the general population with cervical and lumbar pain (Bot et al., 2005; Hoy et al., 2012).

There was a large variation in sample sizes between the studies in this review. Three studies identified small sample size as a limitation in their ability to be confident in their findings, one in relation to the overall sample size (Desouzart et al., 2016) and the other two in relation to specific sleeping postures, for example upright sleeping (Abanobi et al., 2015; Gordon et al., 2007a).

The type of study designs and patient populations identified in this scoping review have provided preliminary information regarding relationships between sleep posture and spinal symptoms, but there were not enough high-quality studies to adequately answer our research question.

6.4.2 Sleep Posture Measurement

The most common adult sleep postures are side lying, supine and prone (De Koninck et al., 1992; Gordon et al., 2004; Haex, 2005), which were the postures examined by the studies in this review (Table 37). Side lying is the sleep posture that greater than 60% of European adults adopt for the majority of the night (De Koninck et al., 1992; Gordon et al., 2004; Haex, 2005). For this reason, one study divided side lying into two sleep postures, based upon symmetry and plausible spinal load, as being either supportive of spinal tissues or provocative. While these authors found no significant relationships between sleep posture and waking spinal symptoms, this may have been due to a lack of power or the temporal mismatch between measuring sleep posture (over two nights) and questions about waking pain (over the prior month). These authors identified a trend that participants spending more time in supportive side lying reported fewer morning symptoms per month, than those sleeping in prone or three quarter side lying (Cary et al., 2016).

All studies in this review utilised self-report to report sleep posture, and in addition, one study used video data to determine sleep posture and compare to self-report (Cary et al., 2016). Self-report is uncertain, as participants are asked to report on posture when they are not fully conscious. Self-report was identified as a limitation by two of the studies in this review (Desouzart et al., 2016; Gordon et al., 2007a) and shown to be inaccurate for supine and intermediate side lying postures in another study (Cary et al., 2016). Self-report has been described as accurate for the sleep postures of side lying, supine and prone (Gordon et al., 2004), however, no validity or reliability data were reported for the classification of sleep postures. In more recent studies examining self-report and sleep posture, when participants were asked to identify their dominant sleep posture, inaccuracy was nearly 33% (Kaplowitz et al., 2015; Yu, 2018). It therefore seems prudent to not rely purely on self-report and clinicians would have greater confidence when advising people with pain about sleep posture, if research included both self-report and a valid and reliable measure of sleep posture, such as included in one study (Cary et al., 2016) and discussed in Chapter 3.

6.4.3 Measurement of Symptoms

Three studies examined specific anatomical areas of the spine and one study examined the spine more generally (Table 38). In the cervical spine, an IVD cleft and oblique ZPJs enhance mobility, but the cervical spine has increased reliance on soft tissues for support. In the lumbar spine, increasingly larger vertebrae and associated structures provide bony stability to ameliorate the higher loads. See Section 2.2.2. With such different functions and anatomical support structures, it is possible that sleep postures will also load spinal structures differently. For this reason, it could be important to separately examine relationships between sleep posture and spinal symptoms, with respect to these two different anatomical areas. For example, studies in this review indicated sleeping in supine was associated with lumbar symptoms (Abanobi et al., 2015), but not associated with cervical symptoms (Gordon et al., 2007a).

Pain was measured in all studies (Table 38), which is appropriate given cervical and lumbar pain are leading contributors across all age groups and countries to musculoskeletal disability (Hurwitz et al., 2018). However, characteristics like intensity, frequency or the onset time of pain were not consistently measured and are important to better understand the overall impact pain is having on daily function (Gordon & Grimmer-Somers, 2010). Stiffness was the second most reported outcome measure in this review. Prior authors have reported stiffness as the most common symptom produced, or not relieved on waking (Gordon & Grimmer-Somers, 2010), indicating it may also be an important outcome measure to consider when examining relationships between sleep posture and waking spinal symptoms.

With regard to the relationship between sleep posture and time of onset of spinal symptoms, only half of the studies examined waking symptoms (Cary et al., 2016; Gordon et al., 2007a). Waking spinal symptoms are rarely present every morning, which may be due to an individual's variation in sleep posture routine. Therefore, to better understand relationships between sleep posture and spinal symptoms, it would be important that spinal symptoms are recorded on first waking and overall several days.

Questionnaires of differing formats were used by all studies in this scoping review (Table 38). Questionnaires provide a simple and efficient method to collect data using validated measures such as VAS in relation to outcome measures. However, the use of NRS is faster and more accurate than a VAS, as there is only one cognitive step in arriving at an answer (Gabel, 2018). To most accurately assess waking spinal symptoms in relation to sleep posture, questionnaire completion should occur promptly on waking.

6.4.4 Results, Conclusions and Recommendations

Three studies found significant relationships between certain sleep postures and spinal symptoms, however, the results of the included studies need to be interpreted with caution. There was a strong gender bias in two studies (Abanobi et al., 2015; Desouzart et al., 2016), a restricted age of included participants in one study (Desouzart et al., 2016) and two studies, did not specifically examine waking spinal symptoms (Abanobi et al., 2015; Desouzart et al., 2016).

Conclusions drawn from three studies indicate an association between some sleep postures and spinal symptoms (Abanobi et al., 2015; Cary et al., 2016; Gordon et al., 2007a) and one study identified the potential benefits of addressing sleep posture with regard to improving spinal pain through sleep posture education (Desouzart et al., 2016). Spinal pain is a major and growing global health problem with increasing rates of disability (Hurwitz et al., 2018), even though increased resources are being utilised (Deyo, Mirza, Turner, & Martin, 2009). For the past 20 years there has been a strong biomedical focus on patho-anatomy as the cause of spinal pain. However, in the case of lumbar pain, in only 8-15% of cases, is a specific tissue identified as the cause (Waddell, 2004). Concurrently, there has been an escalation in imaging, opioid prescription, injections and surgery, with questionable benefit (Atlas, Keller, Wu, Deyo, & Singer, 2005; Friedly, Chan, & Deyo, 2007; Runciman et al., 2012) and higher risks (Luo, Pietrobon, & Hey, 2004; Manchikanti et al., 2009). Changing physical risk factors like type of movement pattern (O'Sullivan, 2005), level of strength and conditioning (Gabel et al., 2018; Micheo, Baerga, & Miranda, 2012) and sustained or repeated postures (Solomonow, Baratta, et al., 2003; Solomonow et al., 2012) , are relatively risk free, cost effective to implement, and show great potential. Sleep posture is an example of a sustained physical risk factor, that is modifiable (Cartwright et al., 1991; van Maanen & de Vries, 2014) with potential to improve spinal symptoms.

Recommendations arising from the four studies in this review generally fell into two areas, those relating to improving clinical outcomes and those aimed to improve future research. The latter is discussed in Section 6.7. In relation to clinical outcomes, it was identified that sleep posture and waking symptoms should be considered part of the clinical reasoning process when developing management plans for people with waking spinal symptoms (Gordon et al., 2007a); that the use of training to change bad sleep postures be considered in an effort to reduce the burden of lumbar pain (Abanobi et al., 2015); and the use of multimodal methods to assess sleep posture (Desouzart et al., 2016). With regard to recommending a sleep posture to minimise spinal symptoms, this review finds that the side lying posture was the most consistent in protecting the cervical spine (Gordon et al., 2007a), and that side lying and supine were the sleep postures recommended for those with lumbar spinal pain (Desouzart et al., 2016). However, there is a lack of high-quality studies from which to draw firm conclusions.

6.5 Limitations

This scoping review was based on a standardised framework (Peters et al., 2015), with the modification of including a critical appraisal of evidence assessment. While the protocol for this scoping review was developed a priori, it was not registered. When commencing this scoping review, registration was not recommended as it is now (Tricco et al., 2018).

6.6 Future Research

Based on the findings of this scoping review, we offer the following recommendations to improve the quality of future research.

- Research samples should be large enough to achieve statistical goals and that sample demographics are representative of those in the general population with cervical and lumbar pain.
- Ideally studies should account for confounding factors such as age and gender through study design or statistical analysis.

- To better understand the effect of sleep posture on spinal symptoms, it would be preferable to differentiate spinal symptoms according to location, rather than considering spinal symptoms as a single group, due to differences in spinal anatomy, function and referral of symptoms.

- It is recommended to divide spinal symptoms into categories such as pain, stiffness and bothersomeness, to determine if one or more have greater clinical relevance. It would also be informative to consider the temporal aspect of spinal symptoms. That is, recording spinal symptoms on first waking before they are influenced by daytime activities.

- The adoption of side lying appears to be protective of cervical and possibly spinal symptoms more generally, however, with most adults spending the majority of the night in side lying, it would be worthwhile further exploring whether subtypes of side lying postures are more appropriate than others.

- Historically, self-report has been used to measure sleep posture, but has been shown to be problematic and future research should use a validated measure of sleep posture.

Sleep posture is potentially modifiable following education (Desouzart et al., 2016). Changing sleep posture through education has been successfully used to manage people with medical and pain related conditions like positional sleep apnoea, spinal stenosis and spinal pain. See Section 2.5.6.2. As a minimally invasive and low-cost intervention, education is a sensible first choice when attempting to change sleep posture. This potential was reported by authors of one study (Abanobi et al., 2015) and should be further explored in future research using larger scale longitudinal studies.

Chapter 7. Discussion

This research has produced the following new knowledge:

1. The identification of a low cost, accurate and reliable method to assess sleep posture, including newly subclassified side lying posturers in the home environment, which does not provoke a first night effect.

2. That participants waking with spinal symptoms, spend more time in provocative sleep postures, especially provocative side lying than the control group.

3. In addition to experiencing increased waking symptoms, participants also experienced poorer quality of sleep.

4. That following a single educational session, participants in the symptomatic group were able to change their sleep posture routine, and spend less time in provocative sleep postures as requested.

5. That at the same time as changing their sleep posture, participants reported a reduction in waking spinal symptoms, less disability and an improvement in the quality of their sleep.

The topic of this PhD thesis, examining the relationships between sleep posture, waking spinal symptoms and quality of sleep, began from a clinical question. Patients reported going to bed with minimal or no spinal symptoms, yet woke with functional limitations due to spinal pain and stiffness. Others complained of restless nights, being unable to achieve a comfortable sleep posture, experiencing poor sleep quality and waking fatigued. Subsequent exploration of these topics identified a large body of anecdotal information, but little research to guide clinical decisions. Consequently, the development of this thesis grew around two key hypotheses.

Our first hypothesis was that the participants waking with spinal symptoms would spend different amounts of time in different sleep postures, in comparison to those participants that did not wake with spinal symptoms. Due to inaccuracies of self-reporting sleep posture, it was necessary to develop and use an objective measure of sleep posture. We developed a new recording method, determined reliability and validity under a range of light and bedding variations in the home environment, and noted that it induced no first night effect. Using this method, we compared a Control group with symptomatic groups (e.g., Cervical and Lumbar) and found differences in the amount of time spent in provocative sleep postures. In addition, when comparing the symptomatic with the Control group, we found significant differences in a range of PROs including disability, quality of sleep, mental health and quality of life.

Our second hypothesis was that with education, an individual’s sleep posture routine could be changed with education and that there would be a concurrent improvement in symptoms and PROs. We found that sleeping posture routines in both the Cervical and Lumbar groups did change following a sleep posture education intervention. At the same time as improvements in sleep posture were noted, waking symptoms and quality of sleep improved in both groups, and these were maintained at 16 weeks. We also found there were improvements in disability, quality of sleep, mental health and quality of life measurements in the Lumbar group and disability in the Cervical group, that were also maintained to 16 weeks after intervention. Improvements in quality of sleep and quality of life measures occurred in the Cervical group, but these were not significant.

Due to the long period of time required to complete this thesis, it was of interest to know whether there had been any significant changes in the body of literature pertaining to sleep posture, spinal symptoms and quality of sleep. To this end we conducted a scoping review in April 2018, see Chapter 6, examining study designs, methodology, recommendations and conclusions. From the scoping review we determined that:

1) Side lying sleep postures are usually considered as one posture
2) Few studies have used an objective measure of sleep posture
3) There is a paucity of literature examining relationships between sleep posture and spinal symptoms and quality of sleep
4) It is unclear whether sleep posture can be changed in response to an education intervention.

The results of the scooping review provided reassurance that the overall research aim and six objectives developed at the commencement of the thesis 8 years prior, remained relevant.

7.1 Accuracy of Self-Report of Sleep Posture Assessment

In our initial literature search and our more recent scoping review, we identified self-report as the most common method of measuring sleep posture (Abanobi et al., 2015; Gordon et al., 2004, 2007a; Noll et al., 2017). However, our pilot study (N = 15) (Cary et al., 2016), indicated that self-reported sleep posture data were not an accurate reflection of sleep posture, see Section 3.6. This finding was confirmed in our larger cross-sectional study, see Section 5.1.2. Other researchers have also identified a lack of accuracy using self-report in up to 33% of participants (Yu, 2018), bringing into question the existing body of literature where sleep posture data has been measured using self-report. Further, those who have used self-report to classify sleep posture commonly ask participants to identify only some aspects of their sleep routine, such as their dominant sleep posture (Abanobi et al., 2015; Noll et al., 2017) or their waking and retiring sleep posture (Gordon et al., 2004, 2007a) leaving posture during the rest of the night unknown.

Using dual infra-red cameras with viewing angles set at 90 degrees to each other to improve visualisation of limb placement, we demonstrated excellent inter- and intra-rater reliability and validity amongst a group of health professionals classifying sleep posture under a variety of light and bedding situations (Cary, Stirling, et al., 2019). In addition to the standard postures of supine and prone, this study included the identification of two sub-classifications of side lying postures, on the basis of plausible spinal soft tissue load. The accuracy and utility of the recording method was confirmed in our field study in home environments (Cary et al., 2016).

7.2 Group Allocation

To address our first hypothesis, we advertised for volunteers who met general selection criteria. During recruitment, the volunteers were divided into 3 groups based on the location (predominantly Cervical or Lumbar) and severity (frequency and intensity) of spinal symptoms. Volunteers that did not meet criteria for a symptomatic group were allocated to the Control group. No volunteers were excluded based on our eligibility criteria. In view of this method of group allocation, it was not surprising to find higher scores on NRS for pain, stiffness and bothersomness in participants of the symptomatic groups compared with the Control group, verifying group allocations. However, it is important to note that at baseline only 22% of participants in the Control group were completely free of waking spinal symptoms in the prior 2 weeks; 39% reported having lumbar, 22% cervical and 13% mid back symptoms, albeit at lower frequency and intensity than symptomatic groups (Table 11). The criteria for inclusion into our symptomatic groups was continuous with our inclusion into the Control group, that is, if their NRS for symptom(s) was three or greater they were allocated into a symptomatic group, if less than three they were allocated into the Control group. If symptoms were worse in the morning and occurred four or more per times per month, they were allocated into a symptom group, if less than four times per month they were allocated into the Control group. Given our method of recruitment, it would be unexpected for participants in our Control group to have absolutely no cervical or lumbar pain. In retrospect, to better clarify differences between our Control and symptomatic groups, it may have been better if we had created a larger division between the groups, that is symptomatic group participants with a symptom NRS of four or more out of 10 and a frequency of eight or more times per month, while participants in the Control group had experienced no spinal symptoms over the past month. This approach may have produced more definitive results, but would have completely excluded some volunteers at enrolment and increased the burden of recruitment.

7.2.1 Other Characteristics of the Groups

The participant characteristics of age, gender, education and BMI were not significantly different across the three groups.

Age is a recognised risk factor for spinal pain, with the incidence of pain increasing with age to a peak incidence of cervical pain occurring between 35 and 49 years of age (Bot et al., 2005; Gordon et al., 2002; Hoy, Protani, De, & Buchbinder, 2010) and lumbar pain between 46 and 64 years of age (Hoy et al., 2012; Kopec et al., 2004). The age of participants in this study ranged from 18 to 45 years and were grouped in 4 - 5 year brackets, similar to the Australian Bureau of Statistics (Statistics, 2016). In retrospect this could have been more closely matched to allow more accurate comparisons. The age of participants was restricted by selection criteria, with the highest incidence of pain being experienced in the 36 to 45 year old age range which is similar to the general population.

There was a higher overall representation of females in our study, which is appropriate given the higher percentage of women in the general population (Statistics, 2018). Some studies (Côté et al., 2004; Hogg-Johnson et al., 2008; Hoy et al., 2012; Manchikanti et al., 2009) but not all studies (Toroptsova, Benevolenskaya, Karyakin, Sergeev, & Erdesz, 1995) have found the prevalence of spinal pain to be higher in females, but we did not find this in our symptomatic groups.

Across the three groups in our sample, BMI was normally distributed and not significantly different between groups. At least 50% of participants in each group had a BMI classification of overweight or obese, which is lower than the general Australian population (Australian Bureau of Statistics, 2019) of 63%, when our data was collected. In one systematic review, BMI was found to be a weak risk factor for LBP (Leboeuf-Yde, 2000) while another study reported that a BMI > 30 (i.e., obese) was associated with an increased occurrence of LBP (Webb et al., 2003). As a result, we would expect BMI to be higher in our Lumbar group but this was not the case, possibly due to our small sample size. A higher BMI is well known to be associated with sleep disorders like OSA (Browman et al., 1984) and those with less body weight are more likely to have higher sleep quality (Bader & Engdal, 2000; Jacobson, Wallace, & Gemmell, 2006). That we didn't find differences in BMI between groups, but did find differences in sleep quality (e.g. NRS quality for sleep, PSQI and ISI) and pain and disability (e.g., SFI, NRS pain) could indicate factors other than BMI were influential.

Across the three groups, the lowest percentage intake of medication was in the Control group. In our symptomatic groups, the most commonly used medications were analgesics, NSAIDs and antidepressants. In a 10 year review of Australian general practitioners' management for new or first episode of neck or LBP, simple analgesics (8%) and NSAIDs (12%) were most commonly prescribed (Michaleff, Harrison, Britt, Lin, & Maher, 2012). Twenty five percent or less of participants in our symptomatic groups reported the use of either analgesia (Cervical 15%, Lumbar 5%), anti-depressant (Cervical 8%, Lumbar 5%) or NSAIDs (Cervical 2%, Lumbar 2%) medication which is much less than 84.4% (mostly analgesic and NSAIDs) used in a group of cLBP pain participants (Marty et al., 2008) and 53.3% (mostly analgesic and NSAIDs) in a group with whiplash associated disorders (Nikles, Yelland, Bayram, Miller, & Sterling, 2017). The higher use of analgesics and NSAIDs may be due to participants recruited in the former study having cLBP and the latter including a percentage of chronic whiplash participants, while participants in our study were recruited based on symptom intensity and frequency, not chronicity.

7.3 Do Participants with Waking Symptoms Sleep Differently?

The findings of this cross-sectional study indicate that people with neck pain do sleep differently to those without neck pain. Participants in the Cervical group spent a greater percentage of the night in PSL and when time in each posture was expressed in absolute values, the Cervical group spent on average twice as long in provocative side lying and three times as long in prone (Table 16). Our results are similar to an epidemiological study examining waking cervical symptoms and sleep posture (Gordon et al., 2007a). The authors found that participants who reported prone as their dominant sleep posture, reported the highest percentage of waking cervical symptoms. An interesting consideration is whether it is the total amount of time or the percentage of time spent in provocative sleep postures, that is more likely to provoke symptoms. A study conducted on feline spines, points towards the amount of time as being important and once a quantity of time is passed, recovery of tissue takes proportionally much longer (Solomonow, Zhou, et al., 2003). In this study, feline spines were subjected to three, 10 minute periods of flexion, with each period followed by 10 minutes of rest. The creep that developed during the flexion loading period, did not recover during the rest period, and the cumulative amount of creep that developed over the three sessions of flexion, did not recover after a 7 hour rest period. While 10 minutes was used in this study, the threshold amount of time would most likely vary in regards to the amount of load and also individual variations in the quality of collagen, as discussed in Section 2.3.2.1.1.

In addition to percentage and total time spent in sleep postures, we examined the frequency of posture shifts, as an indication of postural restlessness and LPPI as an indication of sleep stability. Based on plausible tissue load, one possible reason to change posture more frequently is to offload pain sensitive structures that have been aggravated by certain sleep postures, such as prone and PSL. Spinal and capsular ligaments are highly innervated (Yamashita, Cavanaugh, El-Bohy, Getchell, & King, 1990) and have been shown to produce pro-inflammatory cytokines following sustained or repeated loading in feline studies (Solomonow, 2012). Some studies have examined LPPI (i.e., a posture held for 30 minutes or more) as an indication of sleep stability (De Koninck et al., 1992; Lorrain & De Koninck, 1998). Exploring the idea that some sleep postures may be provocative of spinal symptoms, our study sought to not only measure the frequency aspect of LPPI (i.e., Standard LPPI), but also the posture in which LPPI occurred and the number of 30 minute periods for each LPPI (e.g., Actual LPPI). That is, if one posture was held for 65 minutes, one Standard LPPI was recorded and two, 30 minute Actual LPPI.

In comparison to our Control group, participants in the Cervical group did experience a higher frequency of posture shifts. Pain free adults, of mixed age and gender, have been noted to change posture approximately 12 to 20 times per night (Bader & Engdal, 2000; Chen et al., 2013b; Skarpsno et al., 2017). This frequency of posture shifts is reported to double in those that describing themselves as poor sleepers (De Koninck et al., 1983). However, the number of posture shifts recorded depends on the definition of what constitutes a posture and how long a posture needs to be maintained before it becomes a posture shift. Some authors have considered any limb or spinal segment (i.e., head, trunk, leg or arm) moving a posture shift (De Koninck et al., 1983), others divided shifts into minor and major (Bader & Engdal, 2000) based on intensity of electrical signal, some only noted significant changes in spinal posture (i.e., head, trunk or waist) (Kubota et al., 2003) and others only described posture changes as the 'number of turns' (Chen, Guo, Shen, & Liu, 2013a, p. 109). Some authors required a posture to be sustained for a minute to be defined as a posture (De Koninck et al., 1983; Skarpsno et al., 2017), others between 5 and 30 seconds (Bader & Engdal, 2000 ; Kubota et al., 2003), while others determined a posture as 'when the trunk position was stable' (Gordon & Buettner, 2009, p. 3). We used our validated classification system (see Chapter 3) based on plausible tissue load and classified sleep postures into supine, SSL, PSL and prone. For a posture to be recorded it was sustained for 30 seconds or longer. Participants in our Cervical group changed posture 24 times per night, which is lower than other reported studies, but may reflect differences in the definition of a posture shift as noted above, or the use of a non-validated measure (Bader & Engdal, 2000; Chen et al., 2013b; Gordon & Buettner, 2009; Kubota et al., 2003; Skarpsno et al., 2017) of sleep posture.

With regards to LPPI, participants in the Cervical group spent significantly more LPPI in provocative sleep postures. This result runs contrary to our theory that LPPI were postures of comfort and were therefore sustained for longer periods of time. Participants in the Control group spent more LPPI in non-provocative postures and rather than LPPI being postures of comfort as we presumed, perhaps they are actually postures of habit. To our knowledge, we are the first group to examine the posture in which a LPPI occurred and to note whether this sleep posture was provocative or supportive. We did not find any differences in Actual or Standard LPPI between the Control and symptomatic groups using the common LPPI definition of 30 minute intervals. Given other researchers have noted that spinal tissue creep occurs within 10 minute intervals (Shan et al., 2013; Solomonow, Baratta, et al., 2003), to be more accurate with respect to plausible spinal tissue load, perhaps the concept of LPPI needs to be modified to incorporate shorter time periods.

We only identified one study examining sleep posture and waking cervical symptoms (Gordon et al., 2007a). Self-report was used to determine relationships between dominant sleep posture and waking symptoms. Of participants who mostly slept in supine, 41% reported waking symptoms, of those mostly sleeping in side lying, 45% reported waking symptoms and of those mostly sleeping in prone 47% reported waking symptoms. Prone has been identified by others as provocative (Desouzart, Filgueiras, et al., 2014) of spinal symptoms and in an intervention study, participants were encouraged to avoid it (Desouzart et al., 2016). In our study where sleep posture was objectively measured, Cervical group participants spent 6.4% time in prone which represented the smallest amount of time in any sleep posture. Prior authors classified side lying as a single group, while we divided side lying based on plausible tissue, load into SSL and PSL, in which participants spent 31% and 30% of the night respectively. When adding SSL and PSL together, these results are similar to the side lying classification of prior authors (Gordon et al., 2007a). Our results were also similar (Gordon et al., 2007a), in regards to percentage of time spent sleeping in supine.

Based on plausible tissue loading, we would expect participants in the Lumbar group to spend more time in provocative sleep postures and to change sleep posture more frequently to alleviate symptoms which they did, but it was not significant (p = .052 and p = .071 respectively, Table 21). It is possible that we did not have sufficient statistical power to identify a difference between the Control and Lumbar groups. It is also possible, that as a result of our recruitment criteria, the differences between our Control group and Lumbar group were reduced. For example, at enrolment 45% participants in the Control group nominated having low back pain in the prior 2 weeks.

Authors from two studies, used a single IR camera to record sleep posture and reported on lumbar symptoms as part of a broader examination of diurnal posture (Desouzart, Filgueiras, et al., 2014; Desouzart, Vilar, et al., 2014). One study reported the sleeping postures of healthy males, 18 to 25 years of age, and the other, 19 to 22 year old healthy females. Both groups reported experiencing nocturnal lumbar pain strong enough to disrupt their sleep, being 25% and 50% of participants respectively. Male participants spent 20% of the night in prone, while female participants spent 29% of the night in prone. While not correlated by the authors, the high percentage of reported sleep disruption due to pain and high percentage of time spent sleeping in prone, lends support to our tissue load theory detailed in Section 2.5.4., that certain sleep postures may be provocative of spinal symptoms. Neither of these studies divided side lying into SSL and PSL and so a comparison cannot be made with regards to side lying. Both studies reported greater amounts of time in prone than our Lumbar group (3.9%). There are several possible reasons for this. Firstly, it may be due to their definition of prone, which was the “frontal trunk in contact with the mattress” (Desouzart, Vilar, et al., 2014, p. 668). Our definition was more specific (see Section 3.4.1.2.) in that the frontal trunk needed to be in contact with the mattress and both legs needed to be straight (i.e., knees fully extended). Because of this difference in definitions, some sleep postures classified as prone by Desouzart, Filgueiras, et al. (2014); Desouzart, Vilar, et al. (2014) we would have classified as PSL. Secondly, it may have been due to the lack of using a validated measure of sleep posture (i.e., no reliability or validity data was reported in regards to the sleep postures classifications used). Finally, younger sleepers spend a greater amount of time in prone than older sleepers (De Koninck et al., 1992; Gordon et al., 2007a). Logically, in following this ontogenic trend, our participants of older age would be spending less time in prone. Results from a mixed gender, working aged population study, using triaxial accelerometers, classified sleep posture into front, back and side (Skarpsno et al., 2017). The authors reported participants slept for twice as long in prone than our Lumbar group. Like Desouzart, Filgueiras, et al. (2014); Desouzart, Vilar, et al. (2014), their definition of prone would also have included participants that we classified as sleeping in PSL. Participants in our group spent 34% of the night in supine, which is close to all of these studies, being 25%, 29% and 38% respectively.

In summary, several studies have examined aspects of sleep posture and spinal symptoms, and while direct comparison with our study is difficult for a range of discussed reasons, the studies are part of a growing body of research providing additional evidence that some sleep postures could plausibly have a role in provoking spinal symptoms.

7.4 Is Sleep Posture a Potential Risk Factor?

7.4.1 Spinal Symptoms & Disability

Neck pain and low back pain are global health problems and significant causes of musculoskeletal disability. At baseline, participants in our Cervical and Lumbar group experienced poorer scores in NRS for pain, stiffness and bothersomeness. They also experienced poorer SFI, NDI, RMDQ and SF36-PS scores. The importance of identifying risk factors for the development and recurrence of cervical pain (Kim et al., 2018) and low back pain (Hoy, Brooks, Blyth, & Buchbinder, 2010) has been noted. Risk factors can be considered non-modifiable and modifiable. Modifiable risk factors are able to be changed by individuals or health professionals. The identification of risk factors is important to assist in the identification of individuals predisposed to neck or low back pain and to assist in the development of appropriate education and prevention strategies. In a recent systematic review examining risk factors for first episode neck pain, the most significant physical risk factor was an awkward, sustained posture (Kim et al., 2018). When examining trigger events (i.e., brief exposures) precipitating acute onset LBP, symptom onset was most common in the morning (Steffens et al., 2015); the timing of onset implicates sleep posture and the tissues most likely affected are passive restraints (e.g., ligaments) (Choi, Levitsky, Lloyd, & Stones, 1996). In both studies examining acute onset symptoms, sleep posture was not explored. This lack of research focus on sleep posture and waking spinal symptoms was highlighted in a recent scoping review, in which only four studies were found to address these topics (Cary, Briffa, et al., 2019). It is plausible that awkward, sustained sleep postures cause acute onset cervical or lumbar pain. Sustained posture can injure passive restraints (e.g., ligaments), with the resultant release of pro-inflammatory chemicals (Solomonow, 2012). Sprains and strains, a category that includes passive spinal restraints like ligaments, have a similar pattern of morning onset (Choi et al., 1996). We do not currently know if sleep posture is a possible risk factor for acute onset or recurrent spinal pain, but we have demonstrated in our cross-sectional study, that participants in our symptomatic groups spent more of the night in provocative sleep postures and in our longitudinal study, shown that by reducing the time spent in provocative sleep postures, participants experienced reductions in waking spinal symptoms.

7.4.2 Sleep Quality

An added dimension of our baseline study, related to the assessment of sleep quality which was measured in three ways; NRS for sleep quality over the prior 2 weeks, the PSQI and the ISI. The latter measures are commonly used in the sleep literature and qualify different aspects of sleep quality.

Participants in our Control group reported better (i.e., higher) NRS for sleep quality (Table 12) and better (i.e., lower) PSQI and ISI scores than the Cervical group (Table 13, 14 and 15). Participants in the Control group also spent a greater amount of time in supportive sleep postures than the Cervical group (Table 16). Our results are similar to another study in which the authors found better quality of sleep was associated with the side lying posture (Gordon et al., 2007a).

There were significantly more poor-quality sleepers in the Lumbar group compared with the Control group (Table 13). When comparing mean PSQI scores (Table 20), participants in the Lumbar group (M = 6.6 SD = 3.0) had poor quality sleep, while participants in the Control group (M = 3.2 SD = 1.6) had good quality sleep. Participants in a case-controlled study examining cLBP and sleep quality (Marty et al., 2008) recorded a mean PSQI of 10.9 (SD = 7.9), which is greater than our Lumbar group and may reflect an interaction between chronic pain and sleep quality as discussed in Section 2.4.1.4. We did not measure pain chronicity, only frequency and intensity. In an interventional study of young, healthy adults (Desouzart et al., 2015), participants recorded their PSQI at baseline and at 6 months, having been instructed to sleep in SSL or supine from baseline. At baseline the group's average PSQI score was six, which is very similar to our Lumbar group at baseline. While described as young, healthy adults, 25-50% of the participants reported lumbar pain strong enough to interrupt their sleep (Desouzart, Filgueiras, et al., 2014; Desouzart, Vilar, et al., 2014). It may be because of the reported lumbar pain, that the average group PSQI score is similar to our Lumbar group PSQI score. In another study examining sleep quality (O'Donoghue, Fox, Heneghan, & Hurley, 2009), participants with cLBP were age and gender matched and the PSQI and ISI were used to evaluate sleep quality. Eighty six percent of the cLBP participants were rated as poor-quality sleepers, which is greater than our Lumbar group (70%), but the authors reported a similar occurrence of poor sleepers in their Control group (6%) to our Control group (5%). In this same study, more than half of the participants with cLBP were rated as having threshold clinical insomnia (i.e., ISI score > 13) which is considerable higher than our Lumbar group, in which 20% were rated as having threshold insomnia, indicating our Lumbar group was not experiencing as poor a sleep quality as those with cLBP.

In addition to there being differences in sleep posture (i.e., more time in provocative sleep postures) between our Control group and symptomatic groups and a greater frequency of posture shifts, participants in both of our symptomatic groups had poorer quality sleep. In a large epidemiological study, predictive factors for poor sleep quality and waking cervical symptoms were evaluated (Gordon et al., 2007b). The authors concluded that factors which decrease sleep quality (e.g., medical condition, nocturnal bruxism and past cervical injury) were associated with waking cervical symptoms. Sleep posture was not found to affect sleep quality, however sleep posture was assessed using self-report and this has been found inaccurate. A more recent study, used a single IR camera to examine the effect of changing sleep posture on sleep quality, as part of a three-arm (including control group) interventional study (*n* = 24, 12 female) (Desouzart et al., 2015). Participants in one of the intervention arms were educated to spend more time in supine and SSL, and less in prone. At follow-up, three to four months later, the percentage of time in prone had decreased, percentage time in side lying had increased and participants reported an improvement in sleep quality.

Factors that reduce sleep quality have been shown to increase tissue pain sensitivity and may contribute to why our symptomatic groups reported more pain, stiffness and bothersomness on waking. Prior studies examining sleep posture, have associated posture changes with transitions of sleep stages (Hobson et al., 1978; Muzet et al., 1972). When posture changes occurred, sleepers are more likely to transition into REM and shallow sleep stages, not deep and recovery sleep stages (Section 2.1.2.). What was not considered in these studies, was that shifts in posture may have occurred as a result of plausible tissue loading. Spinal symptoms were not measured in these studies. Our results indicate a relationship between sleep posture and sleep quality. As a result, sleep posture may impact on sleep quality and poorer sleep quality has been linked with broader health issues like depression (Baglioni et al., 2011).

7.4.3 Mental Health

In addition to poorer quality of sleep, we found differences in mental health and quality of life measures between the Control and symptomatic groups at baseline. Participants in the Cervical group, had poorer HADS-A and HADS-D scores, but not SF36 MS. In the Lumbar group, both SF36 MS and HADS-A scores were poorer than the Control group. There is a paucity of literature examining relationships between sleep posture and mental health, however, the broader literature closely associates poor sleep quality with poor mental health in a wide variety of circumstances; problematic smartphone use (Yang, Fu, Liao, & Li, 2019), body fatness in adolescents (Lima et al., 2020), perimenopausal women (Xiao, Mou, & Zhou, 2019) and insomnia risk (Oh, Kim, Na, Cho, & Chu, 2019).

As a result, early intervention programs for insomnia have been recommended due to the strong association between poor sleep and the development of depression (Baglioni et al., 2011). As highlighted in Section 7.4.2., our results indicate a relationship between sleep posture and sleep quality. This has also been noted in a study that used PSG to examine the sleep postures (*n* = 16, 8 female) of self-rated good and poor sleepers (De Koninck et al., 1983). The authors noted that poor sleepers had higher depression scores than good sleepers and concluded that casual links may exist between the quality of sleep and sleep postures.

7.5 Can Participants Change Their Sleep Posture?

Following postural education and an intervention period of 4 weeks, participants in the symptomatic groups were reassessed by video and online questionnaires. Participants in both symptomatic groups were able to significantly reduce the percentage of time they spent in provocative sleep postures and approached the percentages of time spent in each sleep posture recorded by the Control group at baseline (Table 24).

Our pedagogy was simple and clinically reproducible, involving a single face to face discussion and the provision of a reminder handout (Appendix 17). Education has been used before in several studies to affect posture change in relation to changing positional sleep apnea (Cartwright et al., 1991), improving quality of sleep (Desouzart et al., 2015) and in relation to reducing spinal pain (Desouzart et al., 2016). Sample sizes were smaller than our group, *n* = 15, 8 and 10 respectively and intervention periods varied over 8, 12 and 4 weeks respectively. Similar to our intervention, all of these studies provided verbal recommendations to adopt specific sleep postures. Two studies included weekly follow-up periods either by phone or email (Cartwright et al., 1991; Desouzart et al., 2015). Two studies confirmed changes in sleep posture by using a single IR camera (Cartwright et al., 1991; Desouzart et al., 2015) and one by using self-report (Desouzart et al., 2016). Neither of the studies using IR cameras provided reliability and validity data for their sleep posture classifications and neither study sub classified side lying sleep postures and the reliability of self-report is questionable, as discussed in Section 2.5.3.1. Using an objective measure of sleep posture, our study builds on the limited body of current knowledge, that following a single face to face educational session and without follow-ups, clinicians can reasonably expect patients with cervical or lumbar waking spinal symptoms to be able to improve their sleep posture (i.e., reduce the time spent in PSL and increase the time spent in SSL).

7.6 Does Changing Sleep Posture Influence Spinal Symptoms and Disability?

Based on plausible, increased spinal tissue load as a result of sustained or repeated sleep postures, see Section 2.3.2.3.4, we provided postural advice to participants in both symptomatic groups aimed at reducing the time spent in prone and PSL. In line with our original hypothesis, four weeks after the sleep posture education intervention, participants in both symptomatic groups had significant reductions in pain, stiffness and bothersomeness which were clinically important. By 16 weeks after intervention, participants in the Cervical and Lumbar groups reported progressive reductions in pain, stiffness and bothersomeness. Simultaneously, there were significant improvements in associated disability measures for the Cervical group (e.g., NDI, SFI) and Lumbar group (e.g., RMD, SFI, SF36 PC), which were maintained out to 16 weeks and clinically important. It is important to note that baseline disability scores were low in both groups, which is what we expected as our participants were still completing their normal activities of daily living and not seeking treatment, and yet both groups experienced reductions in spinal symptoms and Improvements in disability. Improvements in lumbar pain following a 4 week postural intervention have been noted by others (Desouzart et al., 2016), however determination of sleep posture at baseline and follow-up was by self-report and not confirmed objectively. In another intervention study (Desouzart et al., 2015), with a posture education arm, participants were videoed at baseline and approximately 16 weeks after intervention, however pain and disability measures were not reported.

Using an objective method to measure sleep posture at baseline and after 4 weeks, our study confirms that participants with cervical and lumbar symptoms were able to reduce the time they spent in provocative sleep postures after a posture education intervention and simultaneously, experienced a reduction in pain by 4 weeks, which was maintained out to 16 weeks.

While low back and neck pain are ranked as fourth cause of disability in the world (Hurwitz et al., 2018), the natural course for the majority of people with non-specific mechanical neck pain, is for a general improvement in symptoms over time (Binder, 2007). In a population-based cohort study examining the incidence and course of neck pain over 12 months (Côté et al., 2004), the annual incidence of neck pain was 14.6% with the annual incidence of developing chronic neck pain was 0.6%. The authors noted the course from onset to resolution is marked by periods of exacerbation and remission. A review article (Hoy, Protani, et al., 2010) examining neck pain reported similar findings, with an annual incidence ranging from 10.4% to 21.3% and between 33% to 65% recovered within a year, but the period to recovery was commonly marked by relapses. A study examining the epidemiology of low back pain (Hoy, Brooks, et al., 2010), estimated the 1 year incidence of any LBP ranged from 1.5% to 36% and the 1 year remission ranged from 54% to 80%. The authors also noted that most people experience reoccurrences, which they estimated ranged from 24% to 80% in a 1 year period. In view of this pattern of exacerbation and remission, without a control group, it is impossible for us to be certain if participants in our Cervical and Lumbar groups achieved symptom reduction over the 16 week period as a result of the intervention or time. A larger placebo-controlled trial would be required to establish this with certainty.

7.7 Does Changing Sleep Posture Influence Quality of Sleep?

In both of our symptomatic groups, there were clinically important improvements (Section 5.2.3) in the NRS of sleep quality at 4 and 16 weeks. Participants in both symptomatic groups reported significant improvements in their quality of sleep, as measured by quality of sleep over the prior 2 weeks, at 16 weeks following the sleep posture intervention. Of interest, participants in the Cervical group at 4 weeks had not experienced a significant improvement, while those in the Lumbar group did. In conversation with participants, many mentioned waking during the night and checking their sleep posture for the first few weeks. It may have been that in asking participants to change a habitual sleep routine, their increased sleep posture awareness in the quiet waking and waking sleep stages, known for evaluation, planning and understanding, see Section 2.1.2 reduced their perceived quality of sleep. However, after 16 weeks of practicing their new routine, the initial elevated arousal and perceived disruption in sleep quality, diminished with increased familiarity of their new sleeping routine.

In the prior intervention study with a posture education arm Desouzart et al. (2015) all participants were videoed and completed the PSQI at baseline and after approximately 16 weeks. The education group received posture education involving advice to sleep in either supine with a pillow under the knees, or side lying with a pillow between the knees and between the arms. The other intervention was to practice physiological relaxation before going to sleep. The Control group was advised they may be involved in future surveys. Participants in the posture education and relaxation groups were contacted weekly by phone or email to provide reinforcement and support regarding correct sleeping postures. No contact was made with Control group participants until reassessment. The intervention goal was also similar to ours; reducing time spent in prone and PSL. Because of the specified use of pillows in the posture education group, it is likely that participants classified as sleeping in side lying were sleeping in SSL. However, it is likely that participants classified as sleeping in side lying at baseline, were a mix of PSL and SSL. At 16 weeks, participants in the posture education group had reduced the time spent in prone and increased the time spent in side lying. There was also a reduction in the PSQI score from 6 to 3 points (p = .008). These results mirror our own; that being both symptomatic groups started with a similar PSQI (i.e., 6.6 and 6.0) and following a posture education program, reduced the time spent in provocative sleep postures and at the same time, sleep quality improved at 16 weeks. In our Lumbar group, the PSQI improvement neared significance (p = .055) and the ISI was significant but was not clinically important. In our Cervical group, the magnitude of change was not as large and it is possible that changing sleep posture may not be as influential on sleep quality in people with neck pain or that larger study with a control group may be required to identify changes in the PSQI and ISI. A difference between the Desouzart et al. (2015) study and ours is in relation to follow-up. Participants in our study received no follow-up, other than the educational handout they were provided with when first receiving instructions about changing their sleep posture at the start of the intervention phase. Participants in the Desouzart et al. (2015) study, received a weekly mix of phone calls and/or emails providing positive feedback in regards to the intervention goals. Given the similar outcomes in sleep quality improvement, it may be more efficient and not necessary to provide ongoing follow-up during the intervention phase.

Sleep quality is important because of associations with pain and mental health. Poor quality sleep has been shown to increase susceptibility to episodes, severity and sensitivity of pain (Bigatti et al., 2008; Simpson et al., 2018). In a meta-analysis of longitudinal studies (Baglioni et al., 2011), it was reported that non-depressed people with insomnia, have a twofold risk of developing depression compared with those that did not have insomnia. The authors also reported that people with insomnia were more likely to have depression than the general population and people without insomnia were less likely to have depression that the general population. In our study, we did not find in the Cervical group any significant improvements in HADS-A, HADS-D or SF36 MS measures, even though participants did change their sleep posture and there were improvements in sleep quality and pain as measured by NRS. These results concur with another study examining the use of subjective and objective measures of sleep assessment in a cLBP population (O'Donoghue et al., 2009). They found that if sleep quality was only analysed using one measure, the extent of the altered sleep quality would be inaccurate. The authors reported that subjective measures of sleep quality more closely aligned with subjective pain and quality of life measures, rather than objective measures. Similar discrepancies have been noted in other pain populations (Menefee et al., 2000). It may be that improvements in sleep quality take longer than 16 weeks in people with neck symptoms to have a measurable effect on mental health, given the chronic nature and multidimensional aspects of mental health. Conversely, participants in our Lumbar group experienced significant improvements in all three measures of mental health, which were also clinically significant. This highlights the potential importance of examining cervical and lumbar groups separately, rather than as one single spinal group.

Sleep quality is influenced by initiation and maintenance of sleep. One factor affecting sleep maintenance could be sleep posture. We proposed that sleep posture could be provocative on spinal symptoms, based on plausible tissue load (Section 2.3.2.3.4). We found participants in both symptomatic groups spent more time in provocative sleeping postures and changed sleep posture (lumbar non-significant) more frequently than the Control group. Following a single education session, participants in the symptomatic groups spent less time in provocative postures, changed sleep posture fewer times (cervical non-significant) and experienced improvements in sleep quality. While we cannot be confident that the sleep posture intervention in our study was the cause of improvements in the sleep quality, these improvements do warrant further investigation in future studies.

7.8 Limitations

In the Candidacy proposal and clinical trial registration, our initial aim was to recruit 30 participants into each group. A convenience sample of volunteers were allocated on a consecutive basis to one of the two symptomatic groups based on group eligibility. If they were not eligible for a symptomatic group, they were enrolled in the Control group. Recruitment took considerably longer than expected and the target of 30 participants in each group was unable to be achieved. At the time recruitment was discontinued there were 20 participants in the Control and Lumbar groups and 13 participants in the Cervical group. Having smaller group sizes may have resulted in some findings not reaching significance.

To be able to determine if waking spinal symptoms were caused by sleep posture, we needed to have a control group of symptomatic participants who did not receive the intervention. Randomising symptomatic participants into intervention and control groups would have allowed for potential confounding factors and the influence of time. We recognised in the planning stages, that obtaining sufficient participants in a rural and remote locality to sufficiently power a randomised, controlled study to be unlikely. Rather, we chose to undertake a cross sectional comparison between symptomatic and Control groups and use an uncontrolled, repeated measures design for the intervention study over 16 weeks. This design enabled us to identify differences in sleep posture, symptoms and sleep quality between a Control and symptomatic group participants, determine whether changing sleep posture was a feasible intervention goal and identify if by changing sleep posture, waking spinal symptoms, quality of sleep and other PROs correspondingly changed.

In reviewing sleep posture classifications while reviewing sleep data, it was noted that some participants slept in PSL, with the top leg in greater hip flexion than the lower leg, but remained in a spinal neutral posture due to the specific use of a pillow 'Singapore pillow' or folded duvet. As we were examining plausible spinal load associated with rotation and extension it did not make sense to classify these participants as in PSL. Acknowledging this possibility in the methodological design of future studies would be important.

7.9 Future Research

To better clarify the relationship between sleep posture, waking spinal symptoms and quality of sleep, a randomised clinical trial is recommended. For this to happen, a larger pool of volunteers would be required from which to select eligible participants. Alternatively, a single-subject A-B research design could be used to control for confounding factors. Eligibility criteria for group allocation could be altered to better distinguish between those with and those without waking spinal symptoms.

It is very time consuming to manually observe and score each night of sleep data. While high levels of reliability were reported using this recording method, with larger and more groups, proper resourcing would be necessary. Investigation into the automation of this aspect of data collection, through the use of less intrusive and cost-effective methods in the home environment is warranted. This could incorporate artificial intelligence using a pressure sensitive mattress cover or video data automatically analysed using a sleep posture recognising algorithm, validated with our recording method.

7.10 Conclusion

Primary contact health practitioners are faced with the daily situation of treating patients who are experiencing waking spinal symptoms or exacerbations of already present spinal symptoms. The ability for clinicians to provide evidence-based advice on the possible role of sleep posture, requires a body of literature from which to draw relevant conclusions. We identified, and it has been confirmed by other researchers, that the use of self-report to measure sleep posture is unreliable, bringing into question the existing body of literature that has used this method to assess sleep posture. The first step in examining sleep posture, therefore required the development of a validated measure of sleep posture, that would ideally be portable for use in field situations, rather than limited to sleep laboratories.

Not all sleep postures invoke the same loading pattern, with some maintaining and supporting a symmetrical spine, while others elongate and potentially provoke spinal tissues. The broad classification of side lying has traditionally included all sleep postures that were neither prone or supine, making it the largest sleep posture category. However, based on plausible tissue loading, not all side lying sleep postures are the same. For this reason, we divided side lying into two postures based upon spinal symmetry, one supportive and one provocative. Collagen is a viscoelastic material with capacity to respond to load. However, repeated low loading (e.g., 20 Nm) or sustained loading (e.g., 10 minutes) has been shown in human and animal studies, to cause spinal symptoms (e.g., pain), augmented muscle function (e.g., muscle spasms) and the release of pro-inflammatory chemicals indicating ligamentous damage. These loads and load durations are repeatably achieved in the course of night's sleep.

Our cross-sectional study demonstrated that participants in our symptomatic groups did have a different sleep posture routine to those in the Control group. Participants in the symptomatic groups spent more time in provocative sleep postures, reported more pain, stiffness, bothersomeness, and a poorer quality of sleep. They also reported poorer scores in disability, sleep and quality of life domains.

Following a simple educational intervention, participants in both symptomatic groups were able to reduce the amount of time spent in provocative sleep postures (i.e., PSL and prone), and at the same time experienced a range of improvements in pain and disability measures. Participants in the Lumbar group experienced improvements in nearly all of the PROs.

Our research provides clinicians and researchers with a validated tool to measure sleep posture. It provides clinicians with the knowledge that most patients will be able to reduce the amount of time they spend in provocative sleep postures following a simple sleep posture educational intervention. Our research indicates that changing sleep posture reduces spinal symptoms, disability and improves quality of sleep in patients with cervical or lumbar pain. Further, our research indicates that reducing time in provocative sleep postures may also have broader implications for patients with mental health, that warrants further investigation.

References

Aaronson, S., Rashed, S., Biber, M., & Hobson, J. (1980). Sleeping together: A videotape look at a couples sleep. *Sleep Research, 9*, 120.

Abanobi, O., Ayeni, G., Ezeugwu, C., & Ayeni, O. (2015). Risk-disposing habits of lowback pain amongst welders and panel beaters in Owerri, south-east Nigeria. *Indian Journal of Public Health, 6*, 332-337. doi:10.5958/0976-5506.2015.00164.3

Abraham, J., Sullivan, S., & Ranganathan, S. (2011). *Low-cost and disposable pressure sensor mat for non-invasive sleep and movement monitoring applications.* Paper presented at the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Boston, MA, USA.

Adams, M., Bogduk, N., Burton, K., & Dolan, P. (2006). *The biomechanics of back pain* (2 ed.). Edinburgh: Churchill Livingstone.

Adams, M., & Dolan, P. (1996). Time-dependent changes in the lumbar spine's resistance to bending. *Clinical Biomechanics, 11*(4), 194-200.

Adams, M., Dolan, P., & Hutton, W. (1987). Diurnal variations in the stresses on the lumbar spine. *Spine, 12*(2), 130-137.

Adams, M., Dolan, P., & Hutton, W. (1988). The lumbar spine in backward bending. *Spine, 13*(9), 1019-1026.

Adams, M., & Hutton, W. (1980). The effect of posture on the role of the apophysial joints in resisting intervertebral compressive forces. *Journal of Bone & Joint Surgery (Br.), 62-B*(3), 358-362.

Adams, M., & Hutton, W. (1981). The relevance of torsion to the mechanical derangement of the lumbar spine. *Spine, 6*, 241-248.

Adams, M., & Hutton, W. (1986). The effect of posture on diffusion into lumbar intervertebral discs. *Journal Anatomy, 147*, 121-134.

Adams, M., McMillan, D., Green, T., & Dolan, P. (1996). Sustained loading generates stress concentrations in lumbar intervertebral discs. *Spine, 21*(4), 434-438.

Aggarwal, N., Anand, T., Kishore, J., & Ingle, G. (2013). Low back pain and associated risk factors among undergraduate students of a medical college in Delhi. *Education for Health, 26*(2), 103.

Akerstedt, T., & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience, 52*(1-2), 29-37. doi:10.3109/00207459008994241

Al-Rawi, Z., Al-Aszawi, A., & Al-Chalabi, T. (1985). Joint mobility among university students in Iraq. *Rheumatology, 24*(4), 326-331.

Alsaadi, S., McAuley, J., Hush, J., & Maher, C. (2012). Erratum to: Prevalence of sleep disturbance in patients with low back pain. *European Spine Journal, 21*, 554-560.

Andersson, G. (1981). Epidemiologic aspects on low-back pain in industry. *Spine, 6*(1), 53-60.

Andersson, G. (1999). Epidemiological features of chronic low-back pain. *Lancet, 354*(9178), 581-585. doi:10.1016/S0140-6736(99)01312-4

Anonymous. (2007). Dual therapy while patients sleep. *Advances in Textiles Technology*(April), 8-9.

Anonymous. (2011). Musculoskeletal pain: Research from University of South Australia broadens understanding of musculoskeletal pain. Retrieved from https://search.proquest.com/docview/873246447?accountid=10382

Aprill, C., & Bogduk, N. (1992). The prevalence of cervical zygapophyseal joint pain. A first approximation. *Spine, 17*(7), 744-747.

Arendt-Nielsen, L., Graven-Nielsen, T., Svarrer, H., & Svensson, P. (1996). The influence of low back pain on muscle activity and coordination during gait: A clinical and experimental study. *Pain, 64*(2), 231-240. doi:10.1016/0304-3959(95)00115-8
Ariagno, R., Mirmiran, M., Adams, M., Saporito, A., Dubin, A., & Baldwin, R. (2003). Effect of position on sleep, heart rate variability, and QT interval in preterm infants at 1 and 3 months' corrected age. *Pediatrics, 111*(3), 622-625.
Ariens, G., Van Mechelen, W., Bongers, P., Bouter, L., & Van Der Wal, G. (2000). Physical risk factors for neck pain. *Scandinavian Journal of Work, Environment & Health*, 7-19.
Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal Social Research Methodology, 8*, 19-32. doi:10.1080/1364557032000119616
Arnold, W., Krishna, V., Freimer, M., Kissel, J., & Elsheikh, B. (2012). Prognosis of acute compressive radial neuropathy. *Muscle & Nerve, 45*(6), 893-894. doi:10.1002/mus.23305
Aromataris, E., & Riitano, D. (2014). Systematic reviews: Constructing a search strategy and searching for evidence. *The American Journal of Nursing, 114*, 49-56. doi:10.1097/01.NAJ.0000446779.99522.f6
Assmus, H., Antoniadis, G., Bischoff, C., Hoffmann, R., Martini, A., Preißler, P., . . . Wüstner-Hofmann, M. (2011). Cubital tunnel syndrome – A review and management guidelines. *Zentralbl Neurochir, 72*(02), 90-98. doi:10.1055/s-0031-1271800
Atlas, S., Keller, R., Wu, Y., Deyo, R., & Singer, D. (2005). Long-term outcomes of surgical and nonsurgical management of sciatica secondary to a lumbar disc herniation: 10 year results from the Maine Lumbar Spine Study. *Spine, 30*, 927-935. doi:10.1097/01.brs.0000158954.68522.2a
Overweight and Obesity. (2019). Retrieved from https://www1.health.gov.au/internet/main/publishing.nsf/Content/Overweight-and-Obesity
Auvinen, J., Tammelin, T., Taimela, S., Zitting, P., Järvelin, M., Taanila, A., & Karppinen, J. (2010). Is insufficient quantity and quality of sleep a risk factor for neck, shoulder and low back pain? A longitudinal study among adolescents. *European Spine Journal, 19*(4), 641-649. doi:10.1007/s00586-009-1215-2
Aydin, Z. D., & Cüre, E. (2006). Knowledge and beliefs of Süleyman Demirel University Hospital - Health care personnel on bed rest and semi-recumbent positioning. *Nobel Medicus, 2*(3), 23-27.
Backhaus, J., Junghanns, K., Broocks, A., Riemann, D., & Hohagen, F. (2002). Test–retest reliability and validity of the Pittsburgh Sleep Quality Index in primary insomnia. *Journal of Psychosomatic Research, 53*(3), 737-740.
Backon, J., & Kullok, S. (1990). Why asthmatic patients should not sleep in the right lateral decubitus position. *The British Journal of Clinical Practice, 44*(11), 448-449.
Bader, G., & Engdal, S. (2000). The influence of bed firmness on sleep quality. *Applied Ergonomics, 31*(5), 487-497.
Baglioni, C., Battagliese, G., Feige, B., Spiegelhalder, K., Nissen, C., Voderholzer, U., . . . Riemann, D. (2011). Insomnia as a predictor of depression: A meta-analytic evaluation of longitudinal epidemiological studies. *Journal of Affective Disorders, 135*(1-3), 10-19. doi:10.1016/j.jad.2011.01.011
Barbenel, J., Ferguson-Pell, M., & Beale, A. (1985). Monitoring the mobility of patients in bed. *Medical and Biological Engineering and Computing, 23*(5), 466. doi:10.1007/bf02448935
Barnett, R., & Church, A. (2018). Radial nerve palsy. Retrieved from https://escholarship.org/uc/item/3f16w2j6 doi:org/10.21980/J8KS7F
Bass, C., Planchak, C., Salzar, R., Lucas, S., Rafaels, K., Shender, B., & Paskoff, G. (2007). The temperature-dependent viscoelasticity of porcine lumbar spine ligaments. *Spine, 32*(16), E436-E442.

Bastien, C., Vallieres, A., & Morin, C. (2001). Validation of the Insomnia Severity Index as an outcome measure for insomnia research. *Sleep Medicine, 2*, 297-307.
Batt, M., Tanji, J., & Skattum, N. (1996). Plantar fasciitis: A prospective randomized clinical trial of the tension night splint. *Clinical Journal of Sport Medicine, 6*(3), 158-162.
Beaman, D., Graziano, G., Glover, R., Wojtys, E., & Chang, V. (1993). Substance P innervation of lumbar spine facet joints. *Spine, 18*(8), 1044-1049.
Beaumont, B., & Paice, E. (1992). Back pain. *Occasional Paper Series*(58), 36-38.
Bernstein, I. (1975). Intractable head and neck pain. A possible solution. *New York State Dental Journal, 41*(10), 606-608.
Bibby, S., Fairbank, J., Urban, M., & Urban, J. (2002). Cell viability in scoliotic discs in relation to disc deformity and nutrient levels. *Spine, 27*(20), 2220-2227.
Bigatti, S., Hernandez, A., Cronan, T., & Rand, K. (2008). Sleep disturbances in fibromyalgia syndrome: Relationship to pain and depression. *Arthritis Care & Research, 59*(7), 961-967.
Binder, A. (2007). Cervical spondylosis and neck pain. *BMJ, 334*(7592), 527-531. doi:10.1136/bmj.39127.608299.80
Birrell, F., Adebajo, A., Hazleman, B., & Silman, A. (1994). High prevalence of joint laxity in West Africans. *Rheumatology, 33*(1), 56-59.
Bjelland, I., Dahl, A., Haug, T., & Neckelmann, D. (2002). The validity of the Hospital Anxiety and Depression Scale: An updated literature review. *Journal of Psychosomatic Research, 52*(2), 69-77.
Bland, J. (1987). *Disorders of the cervical spine: Diagnosis and medical management*. Philadelphia: Saunders.
Bogduk, N., & Marsland, A. (1988). The cervical zygapophysial joints as a source of neck pain. *Spine, 13*(6), 610-617.
Bogduk, N., & Mercer, S. (2000). Biomechanics of the cervical spine. I: Normal kinematics. *Clinical Biomechanics, 15*(9), 633-648. doi:10.1016/S0268-0033(00)00034-6
Bogduk, N., & Twomey, L. (1987). *Clinical Anatomy of the Lumbar Spine*. Melbourne: Churchill Livingstone.
Boissonnault, W., & Di Fabio, R. (1996). Pain profile of patients with low back pain referred to physical therapy. *Journal of Orthopaedic & Sports Physical Therapy, 24*(4), 180-191.
Borenstein, D. (2000). Epidemiology, etiology, diagnostic evaluation, and treatment of low back pain. *Current Opinion in Rheumatology, 12*(2), 143-149. doi:10.1097/00002281-200003000-00008
Bot, S., Van der Waal, J., Terwee, C., Van der Windt, D., Schellevis, F., Bouter, L., & Dekker, J. (2005). Incidence and prevalence of complaints of the neck and upper extremity in general practice. *Annals of the Rheumatic Diseases, 64*, 118-123. doi:10.1136/ard.2003.019349
Bove, G., Ransil, B., Lin, H., & Leem, J. (2003). Inflammation induces ectopic mechanical sensitivity in axons of nociceptors innervating deep tissues. *Journal of Neurophysiology, 90*(3), 1949-1955.
Bovenzi, M., & Hulshof, C. (1999). An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986-1997). *Int Arch Occup Environ Health, 72*(6), 351-365. doi:90720351.420 [pii]
Boynton, M., & Goodenough, F. (1930). The posture of nursery school children during sleep. *American Journal of Psychology, 42*, 270-278.
Broderick, J., Junghaenel, D., Schneider, S., Pilosi, J., & Stone, A. (2012). Pittsburgh and Epworth sleep scale items: Accuracy of ratings across different reporting periods. *Behavioral Sleep Medicine, 11*(3), 173-188. doi:10.1080/15402002.2012.654549
Browman, C., Sampson, M., Yolles, S., Gujavarty, K., Weiler, S., Walsleben, J., . . . Mitler, M. (1984). Obstructive sleep apnea and body weight. *Chest, 85*(3), 435-436.

Buchbinder, R., van Tulder, M., Öberg, B., Menezes Costa, L., Woolf, A., Schoene, M., & Croft, P. (2018). Low back pain: A call for action. *Lancet, 391*, 2384-2388. doi:10.1016/S0140-6736(18)30488-4

Buysse, D., Germain, A., Moul, D., Franzen, P., Brar, L., Fletcher, M., . . . Monk, T. (2011). Efficacy of brief behavioral treatment for chronic insomnia in older adults. *Arch Intern Med*(Supplementary Online Content).

Buysse, D., Reynolds, I., Monk, T., Berman, S., & Kupfer, D. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research, 28*, 193-213.

Cabot, S., & Beckham, N. (2005). *Tired of not Sleeping?* Camden: WHAS Pty Ltd.

Cannon, J., & McGill, S. (2015). *Reducing lumbar spine stress during lying postures*. Faculty of Applied Health Sciences, Department of Kinesiology. University of Waterloo. Waterloo.

Carpenter, J., & Andrykowski, M. (1998). Psychometric evaluation of the Pittsburgh Sleep Quality Index. *Journal of Psychosomatic Research, 45*, 5-13.

Carskadon, M., Dement, W., Mitler, M., Guilleminault, C., Zarcone, V., & Spiegel, R. (1976). Self-reports versus sleep laboratory findings in 122 drug-free subjects with complaints of chronic insomnia. *American Journal of Psychiatry, 133*(12), 1382-1388. doi:doi:10.1176/ajp.133.12.1382

Cartwright, R. (1984). Effect of sleep position on sleep apnea severity. *Journal of Sleep Research & Sleep Medicine, 72*(2), 110-114.

Cartwright, R., Lloyd, S., Lilie, J., & Kravitz, H. (1985). Sleep position training as treatment for sleep apnea syndrome: A preliminary study. *Sleep, 8*(2), 87-94. doi:10.1093/sleep/8.2.87

Cartwright, R., Ristanovic, R., Diaz, F., Caldarelli, D., & Alder, G. (1991). A comparative study of treatments for positional sleep apnea. *Sleep, 14*(6), 546-552. doi:10.1093/sleep/14.6.546

Cary, D., Briffa, K., & McKenna, L. (2019). Relationships between sleep posture and non-specific spinal symptoms in adults: A scoping review. *BMJ Open, 9*(6). doi:10.1136/bmjopen-2018-027633

Cary, D., Collinson, R., Sterling, M., & Briffa, K. (2014). Do we know our sleep posture and does sleep posture influence spinal symtpoms? *Sleep and Bilogical Rhythms, 12*, 1-85.

Cary, D., Collinson, R., Sterling, M., & Briffa, K. (2016). Examining the relationship between sleep posture and morning spinal symptoms in the habitual environment using infrared cameras. *Journal of Sleep Disorders: Treatment and Care, 5*. doi:10.4172/2325-9639.1000173

Cary, D., Stirling, M., Collison, R., & Briffa, K. (2019). Examining the reliability and validity of a portable sleep posture assessment protocol, using infrared cameras, under a variety of light and bed cover situations in the home environment. *Work: A Journal of Prevention, Assessment & Rehabilitation, 63*(2). doi:doi 10.3233/WOR-192930

Cavanaugh, J., Lu, Y., Chen, C., & Kallakuri, S. (2006). Pain generation in lumbar and cervical facet joints. *Journal of Bone & Joint Surgery, 88*(suppl_2), 63-67.

Effect Size Calculator. (2018). Retrieved from https://www.cem.org/effect-size-calculator

Chapell, M. (1993). Respiratory problems during sleep in infants and the elderly and possible relation to mattress compression. *Sleep, 16*(4), 391-391.

Chen, Y., Guo, Y., Shen, L., & Liu, S. (2013a). *The quantitative effects of mattress and sleep postures on sleep quality*. Paper presented at the International Asia Conference on Industrial Engineering and Management Innovation, Berlin, Heidelberg.

Chen, Y., Guo, Y., Shen, L., & Liu, S. (2013b). *The quantitative effects of mattress and sleep postures on sleep quality.* Paper presented at the International Asia Conference on Industrial Engineering and Management Innovation, Berlin Heidelberg.

Childs, J., Piva, S., & Fritz, J. (2005). Responsiveness of the numeric pain rating scale in patients with low back pain. *Spine, 30*(11), 1331-1334. doi:10.1097/01.brs.0000164099.92112.29

Cho, Y., Song, Y., Cha, Y., Shin, B., Shin, I., Park, H., . . . Song, M. (2013). Acupuncture for chronic low back pain. *Spine, 38*(7), 549-557.

Chohan, A., Payne, K., Selfe, J., & Richards, J. (2013). Biomechanical testing of a spinal alignment cushion 'Rophi' Cushion in adults with lower back pain. *Gait and Posture, 38*(Suppl. 1), S104. doi:org/10.1016/j.gaitpost.2013.07.211

Choi, B., Levitsky, M., Lloyd, R., & Stones, M. (1996). Patterns and risk factors for sprains and strains in Ontario, Canada 1990: An analysis of the workplace health and safety agency data base. *Journal of Occupational and Environmental Medicine, 38*(4), 379-389.

Copay, A., Glassman, S., Subach, B., Berven, S., Schuler, T., & Carreon, L. (2008). Minimum clinically important difference in lumbar spine surgery patients: A choice of methods using the Oswestry Disability Index, medical outcomes study questionnaire Short Form 36 and pain scales. *The Spine Journal, 8*(6), 968-974. doi:10.1016/j.spinee.2007.11.006

Coppes, M., Marani, E., Thomeer, R., & Groen, G. (1997). Innervation of "painful" lumbar discs. *Spine, 22*(20), 2342-2349.

Corlett, E. (1981). *Pain, posture and performance*. London: Wiley.

Corrigan, B., & March, L. (1984). Cervical spine dysfunction: A pain in the neck. *Patient Management, 8*, 48-53.

Côté, P., Cassidy, J., Carroll, L., & Kristman, V. (2004). The annual incidence and course of neck pain in the general population: A population-based cohort study. *Pain, 112*, 267-273. doi:10.1016/j.pain.2004.09.004

Courtial, D. (1970). The patient with low back pain: Bed positioning. *Hospital Management, 109*(4), 66-70.

Covidence. (2018). Covidence. Melbourne Australia: Veritas Health Innovation. Retrieved from https://www.covidence.org/home

Croft, P., Dunn, K., & Raspe, H. (2006). Course and prognosis of back pain in primary care: The epidemiological perspective. *Pain, 122*, 1-3. doi:10.1016/j.pain.2006.01.023

Croft, P., Lewis, M., Papageorgiou, A., Thomas, E., Jayson, M., Macfarlane, G., & Silman, A. (2001). Risk factors for neck pain: A longitudinal study in the general population. *Pain, 93*, 317-325. doi:10.1016/S0304-3959(01)00334-7

Cyron, B., & Hutton, W. (1981). The behaviour of the lumbar intervertebral disc under repetitive forces. *International Orthopaedics, 5*(3), 203-207. doi:10.1007/BF00266684

Daley, M., Morin, C., LeBlanc, M., Gregoire, J., Savard, J., & Baillargeon, L. (2009). Insomnia and its relationship to health-care utilization, work absenteeism, productivity and accidents. *Sleep Medicine, 10*(4), 427-438. doi:org/10.1016/j.sleep.2008.04.005

De Koninck, J., Gagnon, P., & Lallier, S. (1983). Sleep positions in the young adult and their relationship with the subjective quality of sleep. *Sleep, 6*(1), 52-59.

De Koninck, J., Lorrain, D., & Gagnon, P. (1992). Sleep positions and position shifts in five age groups: An ontogenetic picture. *Sleep, 15*, 143-149. doi:10.1093/sleep/15.2.143

Desouzart, G. (2018, June 13). Personal communication.

Desouzart, G., Filgueiras, E., & Matos, R. (2015). Relationship between postural reeducation technique during sleep and relaxation technique in sleep quality. *Procedia Manufacturing, 3*, 6093-6100.

Desouzart, G., Filgueiras, E., Melo, F., & Matos, R. (2014, July). *Human body-sleep system interaction in residence for university students: Evaluation of interaction patterns using a system to capture video and software with observation of postural behaviors during sleep.* Paper presented at the 5th International Conference on Applied Human Factors and Ergonomics, Kraków, Poland.

Desouzart, G., Matos, R., Melo, F., & Filgueiras, E. (2016). Effects of sleeping position on back pain in physically active seniors: A controlled pilot study. *Work: A Journal of Prevention, Assessment & Rehabilitation, 53*, 235-240. doi:10.3233/WOR-152243

Desouzart, G., Vilar, E., Melo, F., & Matos, R. (2014, June). *Human bed interaction: A methodology and tool to measure postural behavior during sleep of the air force military.*

Paper presented at the 3rd International Conference on Design, User Experience, and Usability, Heraklion, Greece.
Deun, D., Verhaert, V., Willemen, T., Wuyts, J., Verbraecken, J., Exadaktylos, V., . . . Vander Sloten, J. (2012). Biomechanics-based active control of bedding support properties and its influence on sleep. *Work: A Journal of Prevention, Assessment & Rehabilitation, 41*(Supplement 1), 1274-1280. doi:10.3233/WOR-2012-0313-1274
Deyo, R. (1993). Deyo clarifies position. *Physical Therapy, 73*(1), 48-48.
Deyo, R., Battie, M., Beurskens, A., Bombardier, C., Croft, P., Koes, B., . . . Waddell, G. (1998). Outcome measures for low back pain research: A proposal for standardized use. *Spine, 23*(18), 2003-2013.
Deyo, R., Mirza, S., Turner, J., & Martin, B. (2009). Overtreating chronic back pain: Time to back off? *The Journal of the American Board of Family Medicine, 22*, 62-68. doi:10.3122/jabfm.2009.01.080102
Dilley, A., & Bove, G. (2008a). Disruption of axoplasmic transport induces mechanical sensitivity in intact rat C‐fibre nociceptor axons. *The Journal of Physiology, 586*(2), 593-604.
Dilley, A., & Bove, G. (2008b). Resolution of inflammation-induced axonal mechanical sensitivity and conduction slowing in C-fiber nociceptors. *The Journal of Pain, 9*(2), 185-192.
Dodick, D. (2006). Chronic daily headache. *New England Journal of Medicine, 354*(2), 158-165.
Dolan, P., Adams, M., & Hutton, W. (1988). Commonly adopted postures and their effect on the lumbar spine. *Spine, 11*(197-201).
Dolan, P., Earley, M., & Adams, M. (1994). Bending and compressive stresses acting on the lumbar spine during lifting activities. *Journal of Biomechanics, 27*, 1237-1248. doi:10.1016/0021-9290(94)90277-1
Downs, S., & Black, N. (1998). The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *Journal of Epidemiology & Community Health, 52*, 377-384. doi:10.1136/jech.52.6.377
Drakatos, P., Higgins, S., Kosky, C., Muza, R., & Williams, A. (2013). The value of video polysomnography in the assessment of intermittent obstructive sleep apnea. *American Journal of Respiratory and Critical Care Medicine, 187*(10), e18-20.
Drerup, B., & Hierholzer, E. (1987). Automatic localization of anatomical landmarks on the back surface and construction of a body-fixed coordinate system. *Journal of Biomechanics, 20*(10), 961-970. doi:org/10.1016/0021-9290(87)90325-3
Dunkell, S. (1977). *Sleep positions: The night language of the body*. New York: William Morrow and Company.
Dunn, K., & Croft, P. (2005). Classification of low back pain in primary care: Using “bothersomeness” to identify the most severe cases. *Spine, 30*(16), 1887-1892.
Dvorak, J., Antinnes, J., Panjabi, M., Loustalot, D., & Bonomo, M. (1992). Age and gender related normal motion of the cervical spine. *Spine, 17*, S393-S398.
Dvorak, J., Vajda, E., Grob, D., & Panjabi, M. (1995). Normal motion of the lumbar spine as related to age and gender. *European Spine Journal, 4*, 18-23.
Dwyer, T., Ponsonby, A., Blizzard, L., Newman, N., & Cochrane, J. (1995). The contribution of changes in the prevalence of prone sleeping position to the decline in sudden infant death syndrome in Tasmania. *Journal American Medical Association, 273*(10), 783-789. doi:10.1001/jama.1995.03520340039033
Dzhingarov, B. (2017). *Healthiest sleeping positions*. Cape Town: SyndiGate Media Inc.
Eadie, J., van de Water, A., Lonsdale, C., Tully, M., van Mechelen, W., Boreham, C., . . . Hurley, D. (2013). Physiotherapy for sleep disturbance in people with chronic low back

pain: Results of a feasibility randomized controlled trial. *Archives of Physical Medicine and Rehabilitation, 94*(11), 2083-2092.

Eastwood, P. (2009). Personal communication.

Economics, D. A. (2011). *Re-awakening Australia: The economic cost of sleep disorders in Australia, 2010.* Canberra: Deloitte Access Economics.

Edlich, R., Winters, K., Woodard, C., Buschbacher, R., Long, W., Gebhart, J., & Ma, E. (2004). Pressure ulcer prevention. *Journal of Long-term Effects of Medical Implants, 14*(4).

Edwards, J. (2005). The importance of postural habits in perpetuating myofascial trigger point pain. *Acupuncture in Medicine, 23*(2), 77-82.

Ekman, M., Johnell, O., & Lidgren, L. (2005). The economic cost of low back pain in Sweden in 2001. *Acta Orthopaedica, 76*, 275-284. doi:10.1080/00016470510030698

Ekman-Ordeberg, G., Salgeback, S., & Ordeberg, G. (1987). Carpal tunnel syndrome in pregnancy: A prospective study. *Acta Obstetricia et Gynecologica Scandinavica, 66*(3), 233-235. doi:doi:10.3109/00016348709020753

El-Metwally, A., Salminen, J., Auvinen, A., Kautiainen, H., & Mikkelsson, M. (2004). Prognosis of non-specific musculoskeletal pain in preadolescents: A prospective 4-year follow-up study till adolescence. *Pain, 110*(3), 550-559. doi:10.1016/j.pain.2004.03.021

Endel, D. (1987). At last: New ideas on position of the head. *Krankengymnastik, 39*(4), 243-246.

EndNote. (2018) (Version X8). Philadelphia USA: Clarivate Analytics. Retrieved from https://endnote.com/

Ernst, E. (1995). Treatment of acute low back pain. *New England Journal of Medicine, 332*(26), 1786. doi:10.1056/NEJM199506293322612

Escolar-Reina, P., Medina-Mirapeix, F., Gascón-Cánovas, J., Montilla-Herrador, J., Valera-Garrido, J., & Collins, S. (2009). Self-management of chronic neck and low back pain and relevance of information provided during clinical encounters: An observational study. *Archives of Physical Medicine and Rehabilitation, 90*(10), 1734-1739. doi:10.1016/j.apmr.2009.05.012

Excoffon, S., & Wallace, H. (2006). Chiropractic and rehabilitative management of a patient with progressive lumbar disk injury, spondylolisthesis, and spondyloptosis. *Journal of Manipulative and Physiological Therapeutics, 29*(1), 66-71. doi:org/10.1016/j.jmpt.2005.11.010

Farfan, H. (1973). *Mechanical disorders of the low back*. London: Lea & Febiger.

Farfan, H., Cossette, J., Robertson, G., Wells, R., & Kraus, H. (1970). The effects of torsion on the lumbar intervertebral joints: The role of torsion in the production of disc degeneration. *The Journal of Bone & Joint Surgery, 52*(3), 468-497.

Farfan, H., & Gracovetsky, S. (1984). The nature of instability. *Spine, 9*, 714-719.

Feinstein, B., Langton, J., Jameson, R., & Schiller, F. (1954). Experiments on pain referred from deep somatic tissues. *Journal of Bone & Joint Surgery, 36*(5), 981-997.

Feise, R., & Menke, M. (2010). Functional Rating Index: Literature review. *Medical Science Monitor, 16*(2), RA25-36.

Field, A. (2017). *Discovering Statistics Using IBM SPSS Statistics* (5 ed.). Los Angeles: SAGE Publications.

Figueira, E., Chen, T., Agar, A., Coroneo, M., Wilcsek, G., Nemet, A., & Francis, I. (2014). LESCs: Lateralizing Eyelid Sleep Compression Study. *Ophthalmic Plastic & Reconstructive Surgery, 30*(6), 473-475.

Finan, P., Goodin, B., & Smith, M. (2013). The association of sleep and pain: An update and a path forward. *The Journal of Pain, 14*(12), 1539-1552. doi:org/10.1016/j.jpain.2013.08.007

Fischer, B. (1998). Neck and shoulder complaints: A pillow increases well being. *Pflege Zeitschrift, 51*(9), 648-648.

Fleming, P., Gilbert, R., Azaz, Y., Berry, P., Rudd, P., Stewart, A., & Hall, E. (1990). Interaction between bedding and sleeping position in the sudden infant death syndrome: A population based case-control study. *British Medical Journal, 301*(6743), 85-88. doi:10.1136/bmj.301.6743.85

Fletcher, A., Heuvel, C., & Dawson, D. (1999). Sleeping with an electric blanket: Effects on core temperature, sleep, and melatonin in young adults. *Sleep, 22*(3), 313-318. doi:org/10.1093/sleep/22.3.313

Fosse, R., Stickgold, R., & Hobson, J. (2001). Brain-mind states: Reciprocal variation in thoughts and hallucinations. *Psychological Science, 12*(1), 30-36. doi:10.1111/1467-9280.00306

Fossgreen, J. (1977). Physiotherapy of low back pain. *Munchener Medizinische Wochenschrift, 119*(39), 1255-1256.

Frendl, D., & Ware Jr, J. (2014). Patient-reported functional health and well-being outcomes with drug therapy: A systematic review of randomized trials using the SF-36 health survey. *Medical Care, 52*(5), 439-445. doi:10.1097/MLR.000000000000010311

Friedly, J., Chan, L., & Deyo, R. (2007). Increases in lumbosacral injections in the Medicare population: 1994 to 2001. *Spine, 32*, 1754-1760. doi:10.1097/BRS.0b013e3180b9f96e

Fukuda, K., Ogilvie, R., Chilcott, L., Vendittelli, A., & Takeuchi, T. (1998). The prevalence of sleep paralysis among Canadian and Japanese college students. *Dreaming, 8*(2), 59.

Gabel, C. (2018, January 17). Personal communication.

Gabel, C., Melloh, M., Burkett , B., & Michener, L. (2013). The Spine Functional Index (SFI): Development and clinimetric validation of a new whole spine functional outcome measure. *The Spine Journal*. doi:10.1016/j.spinee.2013.09.055

Gabel, C., Mokhtarinia, H., Hoffman, J., Osborne, J., Laakso, E., & Melloh, M. (2018). Does the performance of five back-associated exercises relate to the presence of low back pain? A cross-sectional observational investigation in regional Australian council workers. *BMJ Open, 8*, e020946. doi:10.1136/bmjopen-2017-020946

Garvin, E., Ing, J., Wu, I., & Hsu, E. S. (2014). Pain in pregnancy. 282-289. doi:10.1017/CBO9781107281950.040

Giles, L., & Harvey, A. (1987). Immunohistochemical demonstration of nociceptors in the capsule and synovial folds of human zygapophyseal joints. *Rheumatology, 26*(5), 362-364.

Goldman, S. (2003). Neurogenic positional pedal neuritis. *Journal of the American Podiatric Medical Association, 93*(3), 174-184. doi:10.7547/87507315-93-3-174

Goldman, S. (2005). Nocturnal neuropathic pain in diabetic patients may be caused by spinal stenosis. *Diabetic Medicine, 22*, 1763-1765. doi:10.1111/j.1464-5491.2005.01746.x

Goldsmith, J., Goldsmith, S., & Goldsmith, L. (2000). Postural care at night within a community setting: What the families say. *Journal of the Association of Paediatric Chartered Physiotherapists, 97*, 14-32.

Gordon, S. (2018). Personal communication.

Gordon, S., & Buettner, P. (2009). Age and lateral sleep position: A pilot study. *Internet Journal of Allied Health Sciences and Practice, 7*, 1-5.

Gordon, S., Grimmer, K., & Trott, P. (2004). Self reported versus recorded sleep position: An observational study. *The Internet Journal of Allied Health Science and Practice, 2*, 1-10.

Gordon, S., Grimmer, K., & Trott, P. (2007a). Sleep position, age, gender, sleep quality and waking cervico-thoracic symptoms. *Internet Journal of Allied Health Sciences and Practice, 5*.

Gordon, S., Grimmer, K., & Trott, P. (2007b). Understanding sleep quality and waking cervico-thoracic symptoms. *Internet Journal of Allied Health Sciences and Practice, 5*, 1-12.

Gordon, S., & Grimmer-Somers, K. (2010). Your pillow may not guarantee a good night's sleep or symptom-free waking. *Physiotherapy Canada, 63*, 183-190. doi:10.3138/ptc.2010-13

Gordon, S., Grimmer-Somers, K., & Trott, P. (2009). Pillow use: The behaviour of cervical pain, sleep quality and pillow comfort in side sleepers. *Manual Therapy, 14*(6), 671-678. doi:10.1016/j.math.2009.02.006

Gordon, S., Grimmer-Somers, K., & Trott, P. (2010). Pillow use: The behavior of cervical stiffness, headache and scapular/arm pain. *Journal of Pain Research, 3*, 137-145.

Gordon, S., & Grimmer-Sommers, K. (2011). How well does your own pillow perform? *Journal of Musculoskeletal Pain, 19*(2), 87-94.

Gordon, S., Trott, P., & Grimmer, K. (2002). Waking cervical pain and stiffness, headache, scapular or arm pain: Gender and age effects. *Australian Journal of Physiotherapy 48*. doi:10.1016/S0004-9514(14)60277-4

Gore, D. (2001). Roentgenographic findings in the cervical spine in asymptomatic persons: A ten-year follow-up. *Spine, 26*, 2463-2466.

Gorski, J. (2016, May). *Is the chronic pain generator of tennis elbow a pathological sleep position? A pilot study and a new paradigm for evaluating pain while asleep.* Paper presented at the 8th World Congress of the World Institute of Pain, New York City, NY.

Gorski, J. (2018). Letter to the Editor: Sleep quality in patients with rotator cuff disease. *Journal of the American Academy of Orthopaedic Surgeons, 26*(21), e465-e466. doi:10.5435/JAAOS-D-18-00164

Gracovetsky, S. (1987). The resting spine: A conceptual approach to the avoidance of spinal reinjury during rest. *Physical Therapy, 67*, 549-553.

Grieve, G. (1988). *Common vertebral joint problems* (2 ed.). Edinburgh: Churchill Livingstone.

Grimaldi, A., Mellor, R., Hodges, P., Bennell, K., Wajswelner, H., & Vicenzino, B. (2015). Gluteal tendinopathy: A review of mechanisms, assessment and management. *Sports Medicine, 45*(8), 1107-1119.

Grimmer, K. (1996). The relationship between cervical resting posture and neck pain. *Physiotherapy, 82*(1), 45-51.

Gubin, A., Ulrich, E., Taschilkin, A., & Yalfimov, A. (2009). Etiology of child acute stiff neck. *Spine, 34*(18), 1906-1909.

Haex, B. (2005). *Back and bed: Ergonomic aspects of sleeping*: Boca Raton: CRC Press.

Hansen, K., Weiss, J., & Barton, J. (2002). Recruitment of tendon crimp with applied tensile strain. *Journal of Biomechanical Engineering, 124*(1), 72-77.

Hanten, W., Olson, S., Russell, J., Lucio, R., & Campbell, A. (2000). Total head excursion and resting head posture: Normal and patient comparisons. *Archives of Physical Medicine and Rehabilitation, 81*(1), 62-66. doi:S0003-9993(00)90223-5 [pii]

Harada, T., Sato, T., & Mori, T. (2001). *Pressure distribution image based human motion tracking system using skeleton and surface integration model.* Paper presented at the IEEE International Conference on Robotics and Automation, Seoul, South Korea.

Harrington, C. (2014). *The complete guide to a good night's sleep*. Sydney, NSW: Pan Macmillan.

Harrison, D., Cailliet, R., Harrison, D., Troyanovich, S., & Harrison, S. (1999). A review of biomechanics of the central nervous system Part 1: Spinal canal deformations resulting from changes in posture. *Journal of Manipulative and Physiological Therapeutics, 22*, 227.

Harrison, L., Wilson, S., & Munafò, M. (2014). Exploring the associations between sleep problems and chronic musculoskeletal pain in adolescents: A prospective cohort study. *Pain Research and Management, 19*(5), e139-e145.

Harvey, R., Hadley, N., Gill, T., Beats, B., Gordon, P., Long, D., . . . Tottle, A. (1987). Effects of sleeping with the bed-head raised and of ranitidine in patients with severe peptic oesophagitis. *The Lancet, 330*(8569), 1200-1203. doi:org/10.1016/S0140-6736(87)91332-8

Helmanis, L. (2006). *Sleep Better Naturally*. London: Carlton Books.

Hertz, G., Fast, A., Feinsilver, S., Albertario, C., Schulman, H., & Fein, A. (1992). Sleep in normal late pregnancy. *Sleep, 15*(3), 246-251.

Hestbaek, L., Leboeuf-Yde, C., Kyvik, K., & Manniche, C. (2006). The course of low back pain from adolescence to adulthood: Eight-year follow-up of 9600 twins. *Spine, 31*, 468-472. doi:10.1097/01.brs.0000199958.04073.d9

Hignett, S. (2003). Intervention strategies to reduce musculoskeletal injuries associated with handling patients: A systematic review. *Occupational Environmental Medicine, 60*, e6-e6. doi:0.1136/oem.60.9.e6

Hill, S., & Goldsmith, J. (2010). Biomechanics and prevention of body shape distortion. *Tizard Learning Disability Review, 15*, 15-32. doi:10.5042/tldr.2010.0166

Hobson, J. (2005). Sleep is of the brain, by the brain and for the brain. *Nature, 437*(7063), 1254. doi:10.1038/nature04283

Hobson, J., Spagna, T., & Malenka, R. (1978). Ethology of sleep studied with time-lapse photography: Postural immobility and sleep-cycle phase in humans. *Science, 201*(4362), 1251-1253. doi:10.2307/1746368

Hodges, P., van den Hoorn, W., Dawson, A., & Cholewicki, J. (2009). Changes in the mechanical properties of the trunk in low back pain may be associated with recurrence. *Journal of Biomechanics, 42*(1), 61-66.

Hoe, V., Urquhart, D., Kelsall, H., & Sim, M. (2012). Ergonomic design and training for preventing work-related musculoskeletal disorders of the upper limb and neck in adults. *Cochrane Database Syst Rev*. doi:10.1002/14651858.CD008570.pub2.

Hogg-Johnson, S., van der Velde, G., Carroll, L., Holm, L., Cassidy, J., Guzman, J., . . . Peloso, P. (2008). The burden and determinants of neck pain in the general population. *European Spine Journal, 17*, 39-51. doi:10.1007/s00586-008-0624-y

Holly, L., Kelly, D., Counelis, G., Blinman, T., McArthur, D., & Cryer, H. (2002). Cervical spine trauma associated with moderate and severe head injury: Incidence, risk factors, and injury characteristics. *Journal of Neurosurgery: Spine, 96*(3), 285-291.

Holman, A. (2008). Positional cervical spinal cord compression and fibromyalgia: A novel comorbidity with important diagnostic and treatment implications. *The Journal of Pain, 9*(7), 613-622. doi:org/10.1016/j.jpain.2008.01.339

Hoogendoorn, W., Bongers, P., de Vet, H., Douwes, M., Koes, B., Miedema, M., . . . Bouter, L. (2000). Flexion and rotation of the trunk and lifting at work are risk factors for low back pain: Results of a prospective cohort study. *Spine, 25*(23), 3087-3092.

Horner, H., & Urban, J. (2001). 2001 Volvo award winner in basic science studies: Effect of nutrient supply on the viability of cells from the nucleus pulposus of the intervertebral disc. *Spine, 26*(23), 2543-2549.

Howe, J., Loeser, J., & Calvin, W. (1977). Mechanosensitivity of dorsal root ganglia and chronically injured axons: A physiological basis for the radicular pain of nerve root compression. *Pain, 3*(1), 25-41.

Hoy, D., Bain, C., Williams, G., March, L., Brooks, P., Blyth, F., . . . Buchbinder, R. (2012). A systematic review of the global prevalence of low back pain. *Arthritis & Rheumatism, 64*(6), 2028-2037. doi:10.1002/art.34347

Hoy, D., Brooks, P., Blyth, F., & Buchbinder, R. (2010). The epidemiology of low back pain. *Best Practice & Research Clinical Rheumatology, 24*(6), 769-781.

Hoy, D., Protani, M., De, R., & Buchbinder, R. (2010). The epidemiology of neck pain. *Best Practice & Research Clinical Rheumatology, 24*(6), 783-792. doi:https://doi.org/10.1016/j.berh.2011.01.019

Hsia, C., Liou, K., Aung, A., Foo, V., Huang, W., & Biswas, J. (2009). *Analysis and comparison of sleeping posture classification methods using pressure sensitive bed system.* Paper presented at the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Minneapolis, MN.

Hukins, D., Kirby, M., Sikoryn, T., Aspden, R., & Cox, A. (1990). Comparison of structure, mechanical properties, and functions of lumbar spinal ligaments. *Spine, 15*(8), 787-795.

Hult, L. (1954). Cervical, dorsal and lumbar spinal syndromes: A field investigation of a non-selected material of 1200 workers in different occupations with special reference to disc degeneration and so-called muscular rheumatism. *Acta Orthopaedica Scandinavica, 25*(sup17), 1-102.

Hurwitz, E., Randhawa, K., Yu, H., Côté, P., & Haldeman, S. (2018). The Global Spine Care Initiative: A summary of the global burden of low back and neck pain studies. *European Spine Journal*, 1-6. doi:org/10.1007/s00586-017-5432-9

Iatridis, J., Setton, L., Foster, R., Rawlins, B., Weidenbaum, M., & Mow, V. (1998). Degeneration affects the anisotropic and nonlinear behaviors of human anulus fibrosus in compression. *Journal of Biomechanics, 31*(6), 535-544. doi:10.1016/S0021-9290(98)00046-3

IBM Corporation. (2018). SPSS Statistics for Mac (Version 25.0). New York: Armonk.

Iida, T., Abumi, K., Kotani, Y., & Kaneda, K. (2002). Effects of aging and spinal degeneration on mechanical properties of lumbar supraspinous and interspinous ligaments. *The Spine Journal, 2*(2), 95-100.

Ishihara, H., McNally, D., Urban, J., & Hall, A. (1996). Effects of hydrostatic pressure on matrix synthesis in different regions of the intervertebral disk. *Journal of Applied Physiology, 80*(3), 839-846.

Itasaka, Y., Miyazaki, S., Ishikawa, K., & Togawa, K. (2000). The influence of sleep position and obesity on sleep apnea. *Psychiatry and Clinical Neurosciences, 54*(3), 340-341. doi:10.1046/j.1440-1819.2000.00705.x

Jacobson, B., Boolani, A., Dunklee, G., Shepardson, A., & Acharya, H. (2010). Effect of prescribed sleep surfaces on back pain and sleep quality in patients diagnosed with low back and shoulder pain. *Applied Ergonomics, 42*(1), 91-97. doi:10.1016/j.apergo.2010.05.004

Jacobson, B., Wallace, T., & Gemmell, H. (2006). Subjective rating of perceived back pain, stiffness and sleep quality following introduction of medium-firm bedding systems. *Journal of Chiropractic Medicine, 5*(4), 128-134.

Jenner, J., & Barry, M. (1995). ABC of rheumatology: Low back pain. *British Medical Journal, 310*, 929-932. doi:10.1136/bmj.310.6984.929

Johnson, H., Swan, T., & Wiegand, A. (1930). In what positions do healthy people sleep. *Journal of American Medical Association, 94*(26), 2058-2062.

Jokic, R., Klimaszewski, A., Crossley, M., Sridhar, G., & Fitzpatrick, M. (1999). Positional treatment vs continuous positive airway pressure in patients with positional obstructive sleep apnea syndrome. *Chest, 115*(3), 771-781.

Jordan, K., Dunn, K., Lewis, M., & Croft, P. (2006). A minimal clinically important difference was derived for the Roland-Morris Disability Questionnaire for low back pain. *Journal of clinical epidemiology, 59*(1), 45-52. doi:org/10.1016/j.jclinepi.2005.03.018

Josefson, D. (2001). Kidney stones may be linked with sleep posture. *British Medical Journal, 322*(7293), 1015.

Jull, G., Moore, A., Falla, D., Lewis, J., McCarthy, C., & Sterling, M. (2015). *Grieve's modern musculoskeletal physiotherapy: Vertebral column and peripheral joints* (4 ed.). London: Elsevier.

Kallakuri, S., Singh, A., Chen, C., & Cavanaugh, J. (2004). Demonstration of substance P, calcitonin gene-related peptide, and protein gene product 9.5 containing nerve fibers in human cervical facet joint capsules. *Spine, 29*(11), 1182-1186.

Kaplowitz, K., Blizzard, S., Blizzard, D., Nwogu, E., Hamill, C., Weinreb, R., . . . Loewen, N. (2015). Time spent in lateral sleep position and asymmetry in glaucoma. *Investigative Ophthalmology & Visual Science, 56*(6), 3869-3874. doi:10.1167/iovs.14-16079

Kavey, N., Blitzer, A., Gidro-Frank, S., & Korstanje, K. (1985). Sleeping position and sleep apnea syndrome. *American Journal of Otolaryngology, 6*(5), 373-377. doi:org/10.1016/S0196-0709(85)80015-6

Kellgren, J. (1939). On the distribution of pain arising from deep somatic stucutres with charts of segmental pain areas. *Clinical Science, 4*, 175-190.
Kelsey, J., & White, A. (1980). Epidemiology and impact of low-back pain. *Spine, 5*(2), 133-142.
Kempf, B., & Kongsted, A. (2012). Association between the side of unilateral shoulder pain and preferred sleeping position: A cross-sectional study of 83 Danish patients. *Journal of Manipulative and Physiological Therapeutics, 35*(5), 407-412. doi:org/10.1016/j.jmpt.2012.04.015
Kettler, A., Rohlmann, F., Ring, C., Mack, C., & Wilke, H. (2011). Do early stages of lumbar intervertebral disc degeneration really cause instability? Evaluation of an in vitro database. *European Spine Journal, 20*(4), 578-584.
Khalil, H., Peters, M., Godfrey, C., McInerney, P., Soares, C., & Parker, D. (2016). An evidence‐based approach to scoping reviews. *Worldviews on Evidence‐Based Nursing, 13*(2), 118-123. doi:10.1111/wvn.12144
Khoury, R., Camacho-Lobato, L., Katz, P., Mohiuddin, M., & Castell, D. (1999). Influence of spontaneous sleep positions on nighttime recumbent reflux in patients with gastroesophageal reflux disease. *The American Journal of Gastroenterology, 94*(8), 2069-2073.
Kim, K., Jeoung, J., Park, K., Kim, D., & Ritch, R. (2014). Relationship between preferred sleeping position and asymmetric visual field loss in open-angle glaucoma patients. *American Journal of Ophthalmology, 157*(3), 739-745.
Kim, R., Wiest, C., Clark, K., Cook, C., & Horn, M. (2018). Identifying risk factors for first-episode neck pain: A systematic review. *Musculoskeletal Science and Practice, 33*, 77-83. doi:10.1016/j.msksp.2017.11.007
Kingma, I., Baten, C., Dolan, P., Toussaint, H., van Dieën, J., de Looze, M., & Adams, M. (2001). Lumbar loading during lifting: A comparative study of three measurement techniques. *Journal of Electromyography and Kinesiology, 11*, 337-345. doi:10.1016/0021-9290(94)90277-1
Knutson, K., Rathouz, P., Yan, L., Liu, K., & Lauderdale, D. (2006). Stability of the Pittsburgh Sleep Quality Index and the Epworth Sleepiness questionnaires over 1 year in early middle-aged adults: The CARDIA study. *Sleep, 29*(11), 1503.
Koffel, E., Kroenke, K., Bair, M., Leverty, D., Polusny, M., & Krebs, E. (2016). The bidirectional relationship between sleep complaints and pain: Analysis of data from a randomized trial. *Health Psychology, 35*, 41-49. doi:10.1037/hea0000245
Kopec, J., Sayre, E., & Esdaile, J. (2004). Predictors of back pain in a general population cohort. *Spine, 29*, 70-77. doi:10.1097/01.BRS.0000103942.81227.7F
Korakakis, V., Whiteley, R., Tzavara, A., & Malliaropoulos, N. (2018). The effectiveness of extracorporeal shockwave therapy in common lower limb conditions: A systematic review including quantification of patient-rated pain reduction. *British Journal of Sports Medicine, 52*, 387-407. doi:10.1136/bjsports-2016-097347
Korkala, O., Grönblad, M., Liesi, P., & Karaharju, E. (1985). Immunohistochemical demonstration of nociceptors in the ligamentous structures of the lumbar spine. *Spine, 10*(2), 156-157.
Kornetzky, L., Linden, D., & Berlit, P. (2001). Bilateral sciatic nerve “Saturday night palsy”. *Journal of Neurology, 248*(5), 425-425. doi:10.1007/s004150170187
Kovacs, F., Abraira, V., Peña, A., Martín-Rodríguez, J., Sánchez-Vera, M., Ferrer, E., . . . Muriel, A. (2003). Effect of firmness of mattress on chronic non-specific low-back pain: Randomised, double-blind, controlled, multicentre trial. *The Lancet, 362*(9396), 1599-1604.
Kraemer, J. (2011). *Intervertebral disk diseases: Causes, diagnosis, treatment and prophylaxis* (3 ed.). New York: Thieme Medical Publishers.

Krag, M., Cohen, M., Haugh, L., & Pope, M. (1990). Body height change during upright and recumbent posture. *Spine, 15*(3), 202-207.

Krismer, M., Haid, C., & Rabl, W. (1996). The contribution of anulus fibers to torque resistance. *Spine, 21*(22), 2551-2557.

Kronholm, E., Alanen, E., & Hyyppä, M. (1987). Sleep movements and poor sleep in patients with non-specific somatic complaints: No first-night effect in poor and good sleepers. *Journal of Psychosomatic Research, 31*(5), 623-629. doi:org/10.1016/0022-3999(87)90041-9

Kubota, T., Ohshima, N., Kunisawa, N., Murayama, R., Okano, S., & Mori - Okamoto, J. (2003). Characteristic features of the nocturnal sleeping posture of healthy men. *Sleep and Biological Rhythms, 1*(2), 183-185.

Kumar, S. (1990). Cumulative load as risk factor for low-back pain. *Spine, 15*(12), 1311-1316.

Kumar, S. (2001). Theories of musculoskeletal injury causation. *Ergonomics, 44*, 17-47. doi:10.1080/00140130120716

Kuo, C., Yang, F., Tsai, M., & Lee, M. (2004). Artificial neural networks based sleep motion recognition using night vision cameras. *Biomedical Engineering: Applications, Basis and Communications, 16*(02), 79-86.

Kurlak, L. (2014). Sleep Cycle Diagrams. Retrieved from https://gdblogs.shu.ac.uk/b2006900/2014/10/08/sleep-cycle-diagrams/

Kwan, M., Wall, E., Massie, J., & Garfin, S. (1992). Strain, stress and stretch of peripheral nerve rabbit experiments in vitro and in vivo. *Acta Orthopaedica Scandinavica, 63*(3), 267 - 272.

LaBan, M., Viola, S., Femminineo, A., & Taylor, R. (1990). Restless legs syndrome associated with diminished cardiopulmonary compliance and lumbar spinal stenosis: A motor concomitant of" Vesper's curse". *Archives of Physical Medicine and Rehabilitation, 71*(6), 384-388.

Lang, P. (1999). Low back pain: What every person should know. *The Neurologist, 5*(5), 291. doi:10.1097/00127893-199909000-00007

Larsson, L., Baum, J., & Mudholkar, G. (1987). Hypermobility: Features and differential incidence between the sexes. *Arthritis & Rheumatism, 30*(12), 1426-1430.

Lavigne, G., Nashed, A., Manzini, C., & Carra, M. (2011). Does sleep differ among patients with common musculoskeletal pain disorders? *Current Rheumatology Reports, 13*(6), 535.

Lavin, R., Pappagallo, M., & Kuhlemeier, K. (1997). Cervical pain: A comparison of three pillows. *Archives in Physical Medicine and Rehabilitation, 78*(2), 193-198. doi:S0003-9993(97)90263-X [pii]

LeBlanc, A., Evans, H., Schneider, V., Wendt III, R., & Hedrick, T. (1994). Changes in intervertebral disc cross-sectional area with bed rest and space flight. *Spine, 19*(7), 812-817.

Leboeuf-Yde, C. (2000). Body weight and low back pain: A systematic literature review of 56 journal articles reporting on 65 epidemiologic studies. *Spine, 25*(2), 226.

Lee, J., Choi, H., Yang, S., Cho, W., Lee, S., Chung, H., . . . Kim, D. (2011). True neurogenic thoracic outlet syndrome following hyperabduction during sleep: A case report. *Annals of Rehabilitation Medicine, 35*(4), 565-569. doi:10.5535/arm.2011.35.4.565

Lee, J., Shin, J., Yoo, H., Lee, J., Lee, Y., Kim, M., . . . Ha, I. (2016). Short-term effects of a functional cervical pillow on inpatients with neck discomfort: A randomized controlled trial. *International Journal of Clinical and Experimental Medicine, 9*(6), 11397-11408.

Lee, W., & Ko, M. (2017). Effect of sleep posture on neck muscle activity. *Journal of Physical Therapy Science, 29*(6), 1021-1024. doi:10.1589/jpts.29.1021

Leilnahari, K., Fatouraee, N., Khodalotfi, M., Sadeghein, M., & Kashani, Y. (2011). Spine alignment in men during lateral sleep position: Experimental study and modeling. *Biomedical Engineering Online, 10*. doi:10.1186/1475-925x-10-103

Levac, D., Colquhoun, H., & O'Brien, K. (2010). Scoping studies: Advancing the methodology. *Implementation Science, 5*, 9. doi:10.1186/1748-5908-5-69

Liao, W., & Yang, C. (2008). *Video-based activity and movement pattern analysis in overnight sleep studies.* Paper presented at the 19th International Conference on Pattern Recognition, Tampa, Florida. USA.

Lichstein, K., Stone, K., Donaldson, J., Nau, S., Soeffing, J., Murray, D., . . . Aguillard, R. (2006). Actigraphy validation with insomnia. *Sleep, 29*(2), 232-239. doi:10.1093/sleep/29.2.232

Lima, R., de Barros, M., Dos Santos, M., Machado, L., Bezerra, J., & Soares, F. (2020). The synergic relationship between social anxiety, depressive symptoms, poor sleep quality and body fatness in adolescents. *J Affect Disord, 260*(1573-2517 (Electronic)), 200-205. doi:10.1016/j.jad.2019.08.074

Linton, S., Hellsing, A., & Halldén, K. (1998). A population-based study of spinal pain among 35-45-year-old individuals: Prevalence, sick leave, and health care use. *Spine, 23*(13), 1457-1463.

Liu, Y., Goel, V., Dejong, A., Njus, G., Nishiyama, K., & Buckwalter, J. (1985). Torsional fatigue of the lumbar intervertebral joints. *Spine, 10*(10), 894-900.

Lobbezoo, F., Thon, M., Remillard, G., Montplaisir, J., & Lavigne, G. (1996). Relationship between sleep, neck muscle activity, and pain in cervical dystonia. *Canadian Journal of Neurological Sciences, 23*(4), 285-290.

Lomaglio, M., & Canale, B. (2017). Differential diagnosis and recovery of acute bilateral foot drop in a patient with a history of low back pain: A case report. *Physiotherapy Theory and Practice, 33*(6), 508-514. doi:10.1080/09593985.2017.1323358

Lord, S., Barnsley, L., Wallis, B., McDonald, G., & Bogduk, N. (1996). Percutaneous radio-frequency neurotomy for chronic cervical zygapophyseal-joint pain. *New England Journal of Medicine, 335*(23), 1721-1726.

Lorrain, D., & De Koninck, J. (1998). Sleep position and sleep stages: Evidence of their independence. *Sleep, 21*(4), 335-340.

Lotem, M., Fried, A., Levy, M., Solzi, P., Najenson, T., & Nathan, H. (1971). Radial palsy following muscular effort: A nerve compression syndrome possibly related to a fibrous arch of the lateral head of the triceps. *The Journal of Bone and Joint Surgery. (Br.), 53*(3), 500-506.

Lovett, A. (1903). A contribution to the study of the mechanics of the spine. *American Journal of Anatomy, 2*, 457-462.

Low, F., Chua, M., Lim, P., & Yeow, C. (2017). Effects of mattress material on body pressure profiles in different sleeping postures. *Journal of Chiropractic Medicine, 16*(1), 1-9.

Lu, L., Tamura, T., & Togawa, T. (1999). Detection of body movements during sleep by monitoring of bed temperature. *Physiological Measurement, 20*(2), 137.

Lundborg, G., & Rydevik, B. (1973). Effects of stretching the tibial nerve of the rabbit: A preliminary study of the intraneural circulation and the barrier function of the perineurium. *Journal of Bone & Joint Surgery (Br.), 55-B*(2), 390-401.

Luo, X., Pietrobon, R., & Hey, L. (2004). Patterns and trends in opioid use among individuals with back pain in the United States. *Spine, 29*, 884-890.

MacDowall, A., Skeppholm, M., Robinson, Y., & Olerud, C. (2018). Validation of the visual analog scale in the cervical spine. *Journal of Neurosurgery: Spine, 28*(3), 227-235. doi:10.3171/2017.5.SPINE1732

Magnusson, M., Pope, M., Wilder, D., & Areskoug, B. (1996). Are occupational drivers at an increased risk for developing musculoskeletal disorders? *Spine, 21*(6), 710-717.

Magora, A. (1974). Investigation of the relation between low back pain and occupation: Medical history and symptoms. *Scandinavian Journal of Rehabilitation Medicine, 6*(2), 81-88.

Manchikanti, L., Boswell, M., Singh, V., Pampati, V., Damron, K., & Beyer, C. (2004). Prevalence of facet joint pain in chronic spinal pain of cervical, thoracic, and lumbar regions. *BMC Musculoskeletal Disorders, 5*(1), 15.
Manchikanti, L., Singh, V., Datta, S., Cohen, S., & Hirsch, J. (2009). Comprehensive review of epidemiology, scope, and impact of spinal pain. *Pain Physician, 12*, 35-70.
March, L., Francis, H., & Webb, J. (1988). Benign joint hypermobility with neuropathies: Documentation and mechanism of median, sciatic, and common peroneal nerve compression. *Clinical Rheumatology, 7*(1), 35-40. doi:10.1007/bf02284054
Marin, R., Cyhan, T., & Miklos, W. (2006). Sleep disturbance in patients with chronic low back pain. *American Journal of Physical Medicine and Rehabilitation, 85*(5), 430-435. doi:10.1097/01.phm.0000214259.06380.79
Marin, T., Taylor, A., & Gill, T. (2009). *A population profile of auality of life in South Australia: Population norms for 2008 using the SF36 version 2*. Adelaide: South Australian Department of Health.
Marks, R. (1989). Distribution of pain provoked from lumbar facet joints and related structures during diagnostic spinal infiltration. *Pain, 39*(1), 37-40.
Maroudas, A., Stockwell, R., Nachemson, A., & Urban, J. (1975). Factors involved in the nutrition of the human lumbar intervertebral disc: Cellularity and diffusion of glucose in vitro. *Journal of Anatomy, 120*(1), 113.
Marras, W. (2000). Occupational low back disorder causation and control. *Ergonomics, 43*(7), 880-902.
Marty, M., Rozenberg, S., Duplan, B., Thomas, P., Duquesnoy, B., & Allaert, F. (2008). Quality of sleep in patients with chronic low back pain: A case-control study. *European Spine Journal, 17*(6), 839-844.
Mast, B. (1997). Healing in other tissues. *Surgical Clinics, 77*(3), 529-547.
Matsuura, N., Yamao, M., Sugita, A., Aritomi, R., & Shirakawa, S. (2008). Survey of cervical curve and sleep-onset-posture in Japanese. *Journal of Sleep Research, 17*, 143-144.
Mattucci, S., Moulton, J., Chandrashekar, N., & Cronin, D. (2012). Strain rate dependent properties of younger human cervical spine ligaments. *Journal of the Mechanical Behavior of Biomedical Materials, 10*, 216-226. doi:org/10.1016/j.jmbbm.2012.02.004
McDonnell, J. (1945). Sleep posture: Its implications. *The British Journal of Physical Medicine, 9*, 46-52.
McGill, S., & Kippers, V. (1994). Transfer of loads between lumbar tissues during the flexion-relaxation phenomenon. *Spine, 19*(19), 2190-2196.
McGrane, N., Galvin, R., Cusack, T., & Stokes, E. (2015). Addition of motivational interventions to exercise and traditional physiotherapy: A review and meta-analysis. *Physiotherapy, 101*(1), 1-12.
McKenzie, R., & May, S. (2006). *The cervical & thoracic spine: Mechanical diagnosis and therapy* (Vol. 1). Raumati: Spinal Publications, New Zealand.
McMillan, D., Garbutt, G., & Adams, M. (1996). Effect of sustained loading on the water content of intervertebral discs: Implications for disc metabolism. *Annals of the Rheumatic Diseases, 55*(12), 880-887.
McNally, D., Adams, M., & Goodship, A. (1993). Can intervertebral disc prolapse be predicted by disc mechanics? *Spine, 18*(11), 1525-1530.
Meerlo, P., Sgoifo, A., & Suchecki, D. (2008). Restricted and disrupted sleep: Effects on autonomic function, neuroendocrine stress systems and stress responsivity. *Sleep Medicine Reviews, 12*(3), 197-210. doi:10.1016/j.smrv.2007.07.007
Menefee, L., Frank, E., Doghramji, K., Picarello, K., Park, J., Jalali, S., & Perez-Schwartz, L. (2000). Self-reported sleep quality and quality of life for individuals with chronic pain conditions. *The Clinical Journal of Pain, 16*(4), 290-297.
Michaleff, Z., Costa, L., Moseley, A., Maher, C., Elkins, M., Herbert, R., & Sherrington, C. (2011). CENTRAL, PEDro, PubMed, and EMBASE are the most comprehensive databases

indexing randomized controlled trials of physical therapy interventions. *Physical Therapy, 91*, 190-197. doi:10.2522/ptj.20100116
Michaleff, Z., Harrison, C., Britt, H., Lin, C.-W. C., & Maher, C. (2012). Ten-year survey reveals differences in GP management of neck and back pain. *European Spine Journal, 21*(7), 1283-1289. doi:10.1007/s00586-011-2135-5
Micheo, W., Baerga, L., & Miranda, G. (2012). Basic principles regarding strength, flexibility, and stability exercises. *Pm&r, 4*, 805-811. doi:10.1016/j.pmrj.2012.09.583
Miller, R. (1984). The prone sleeper's spine. *British Osteopathic Journal, 16*, 61-68.
Millman, R. (2005). Excessive sleepiness in adolescents and young adults: Causes, consequences, and treatment strategies. *Pediatrics, 115*(6), 1774-1786. doi:10.1542/peds.2005-0772
Mills, G. (1994). Sleeping positions adopted by pregnant women of more than 30 weeks gestation. *Anaesthesia, 49*(3), 249-250.
Mimura, M., Panjabi, M., Oxland, T., Crisco, J., Yamamoto, I., & Vasavada, A. (1994). Disc degeneration affects the multidirectional flexibility of the lumbar spine. *Spine, 19*(12), 1371-1380.
Miura, T., Panjabi, M., & Cripton, P. (2002). A method to simulate in vivo cervical spine kinematics using in vitro compressive preload. *Spine, 27*(1), 43-48.
Monroe, L. (1967). Psychological and physiological differences between good and poor sleepers. *Journal of Abnormal Psychology, 72*(3), 255 - 264.
Monroe, L. (1969). Transient changes in EEG sleep patterns of married good sleepers: The effects of altering sleeping arrangement. *Psychophysiology, 6*(3), 330-337. doi:10.1111/j.1469-8986.1969.tb02910.x
Mooney, V., Cairns, D., & Robertson, J. (1976). A system for evaluating and treating chronic back disability. *Western Journal of Medicine, 124*(5), 370.
Moore, K., Dalley, A., & Agur, A. (2006). *Clinically oriented anatomy* (5 ed.). Philadelphia: Lippincott Williams & Wilkins.
Morin, C., Belleville, G., Belanger, L., & Ivers, H. (2011). The Insomnia Severity Index: Psychometric indicators to detect insomnia cases and evaluate treatment response. *Sleep, 34*(5), 601-608.
Moroney, S., Schultz, A., Miller, J., & Andersson, G. (1988). Load-displacement properties of lower cervical spine motion segments. *Journal of Biomechanics, 21*(9), 769-779.
Murayama, R., Kubota, T., Kogure, T., & Aoki, K. (2011). The effects of instruction regarding sleep posture on the postural changes and sleep quality among middle-aged and elderly men: A preliminary study. *Bioscience Trends, 5*(3), 111-119. doi:10.5582/bst.2011.v5.3.111
Muzet, A., Naitoh, P., Townsend, R., & Johnson, L. (1972). Body movements during sleep as a predictor of stage change. *Psychonomic Science, 29*(1), 7-10. doi:10.3758/BF03336549
N.I.C.E. (2007). *Behaviour change: The principles for effective interventions*. London: National Institute for Clinical Excellence.
Nachemson, A., & Elfstrom, G. (1970). Intravital dynamic pressure measurements in lumbar discs. *Scandinavian Journal of Rehabilitation Medicine, 2*(suppl 1), 1-40.
Nachemson, A., Lewin, T., Maroudas, A., & Freeman, M. (1970). In vitro diffusion of dye through the end-plates and the annulus fibrosus of human lumbar inter-vertebral discs. *Acta Orthopaedica Scandinavica, 41*(6), 589-607.
Nikles, J., Yelland, M., Bayram, C., Miller, G., & Sterling, M. (2017). Management of Whiplash Associated Disorders in Australian general practice. *BMC Musculoskeletal Disorders, 18*(1), 551. doi:10.1186/s12891-017-1899-0
Nitter, A., Pripp, A., & Forseth, K. (2012). Are sleep problems and non-specific health complaints risk factors for chronic pain? A prospective population-based study with 17 year follow-up. *Scandinavian Journal of Pain, 3*(4), 210-217. doi:org/10.1016/j.sjpain.2012.04.001

Noll, M., Candotti, C., Rosa, B., Valle, M., Antoniolli, A., Vieira, A., & Loss, J. (2017). High prevalence of inadequate sitting and sleeping postures: A three-year prospective study of adolescents. *Scientific Reports, 7*, 14929.

Norman, G., Sloan, J., & Wyrwich, K. (2003). Interpretation of changes in health-related quality of life: The remarkable universality of half a standard deviation. *Medical Care*, 582-592. doi:10.1097/01.MLR.0000062554.74615.4C

Norman, R., Wells, R., Neumann, P., Frank, J., Shannon, H., & Kerr, M. (1998). Comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clinical Biomechanics, 13*(8), 561-573.

O'Donoghue, G., Fox, N., Heneghan, C., & Hurley, D. (2009). Objective and subjective assessment of sleep in chronic low back pain patients compared with healthy age and gender matched controls: A pilot study. *BMC Musculoskeletal Disorders, 10*(1). doi:10.1186/1471-2474-10-122

O’Sullivan, P. (2005). Diagnosis and classification of chronic low back pain disorders: Maladaptive movement and motor control impairments as underlying mechanism. *Manual Therapy, 10*(4), 242-255. doi:10.1016/j.math.2005.07.001

O’Sullivan, P., Dankaerts, W., Burnett, A., Farell, G., Jefford, E., Naylor, C., & O’Sullivan, K. (2006). Effect of different upright sitting postures on spinal-pelvic curvature and trunk muscle activation in apain-free population. *Spine, 31*(19).

Oh, C., Kim, H., Na, H., Cho, K., & Chu, M. (2019). The effect of anxiety and depression on sleep quality of individuals with high risk for insomnia: A population-based study. *Front Neurol., 10*, 849. doi:10.3389/fneur.2019.00849

Ohayon, M. (2002). Epidemiology of insomnia: What we know and what we still need to learn. *Sleep Medicine Reviews, 6*(2), 97-111. doi:10.1053/smrv.2002.0186

Olivo, S., Macedo, L., Gadotti, I., Fuentes, J., Stanton, T., & Magee, D. (2008). Scales to assess the quality of randomized controlled trials: A systematic review. *Physical Therapy, 88*, 156-175. doi:10.2522/ptj.20070147

Onen, S., Alloui, A., Gross, A., Eschallier, A., & Dubray, C. (2001). The effects of total sleep deprivation, selective sleep interruption and sleep recovery on pain tolerance thresholds in healthy subjects. *Journal of Sleep Research, 10*(1), 35-42.

Oxland, T. (2016). Fundamental biomechanics of the spine: What we have learned in the past 25 years and future directions. *Journal of Biomechanics, 49*, 817-832. doi:10.1016/j.jbiomech.2015.10.035

Oxland, T., & Panjabi, M. (1992). The onset and progression of spinal injury: A demonstration of neutral zone sensitivity. *Journal of Biomechanics, 25*(10), 1165-1172. doi:10.1016/0021-9290(92)90072-9

What is pain? (2017). Retrieved from http://www.painaustralia.org.au/about-pain/what-is-pain

Panjabi, M. (1992). The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. *Journal of Spinal Disorders, 5*, 383-383.

Panjabi, M., & Brand, J. R. (1976). Mechanical properties of the human thoracic spine as shown by three-dimensional load-displacement curves. *The Journal of Bone and Joint Surgery (Am.), 58*(5), 642-652.

Panjabi, M., Krag, M., White, A., & Southwick, W. (1977). Effects of preload on load displacement curves of the lumbar spine. *The Orthopedic Clinics of North America, 8*(1), 181-192.

Pankhurst, F., & Home, J. (1994). The influence of bed partners on movement during sleep. *Sleep, 17*(4), 308-315.

Park, D., Kim, J., Lee, E., Han, M., & Hur, J. (1999). A newly designed cervical pillow and comparative study. *Journal of Korean Academy of Rehabilitation Medicine, 23*(2), 411-417.

Park, S., Lee, H., Hong, K., & Kim, J. (2001). Evaulation of mattress for the Koreans. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 45*(7), 727-730. doi:org/10.1177/154193120104500711

Patrick, D., Deyo, R., Atlas, S., Singer, D., Chapin, A., & Keller, R. (1995). Assessing health-related quality of life in patients with sciatica. *Spine, 20*(17), 1899-1908; discussion 1909.

Pearcy, M., & Tibrewal, S. (1984). Lumbar intervertebral disc and ligament deformations measured in vivo. *Clinical Orthopaedics and Related Research, 191*, 281-286.

Permut, I., Diaz-Abad, M., Chatila, W., Crocetti, J., Gaughan, J., D'Alonzo, G., & Krachman, S. (2010). Comparison of positional therapy to CPAP in patients with positional obstructive sleep apnea. *Journal of Clinical Sleep Medicine, 6*(3), 238.

Peters, M., Godfrey, C., Khalil, H., McInerney, P., Parker, D., & Soares, C. (2015). Guidance for conducting systematic scoping reviews. *International Journal of Evidence Based Healthcare, 13*, 141-146. doi:10.1097/XEB.0000000000000050

Philip, P., Sagaspe, P., Lagarde, E., Leger, D., Ohayon, M., Bioulac, B., . . . Taillard, J. (2010). Sleep disorders and accidental risk in a large group of regular registered highway drivers. *Sleep Medicine, 11*(10), 973-979. doi:org/10.1016/j.sleep.2010.07.010

Phillips, B., Okeson, J., Paesani, D., & Gilmore, R. (1986). Effect of sleep position on sleep apnea and parafunctional activity. *Chest, 90*(3), 424-429.

Pino, E., Dorner De la Paz, A., Aqueveque, P., Chavez, J., & Moran, A. (2013). *Contact pressure monitoring device for sleep studies.* Paper presented at the 35th Annual Intenational Conference of the IEEE Engineering in Medicine and Biological Society, Osaka, Japan.

Pintar, F., Yoganandan, N., & Voo, L. (1998). Effect of age and loading rate on human cervical spine injury threshold. *Spine, 23*(18), 1957-1962.

PitchingNow. (2014). Stress strain curve. In: PitchingNow.

Pollintine, P., Dolan, P., Tobias, J., & Adams, M. (2004). Intervertebral disc degeneration can lead to “stress-shielding” of the anterior vertebral body: A cause of osteoporotic vertebral fracture? *Spine, 29*(7), 774-782.

Pollintine, P., Przybyla, A., Dolan, P., & Adams, M. (2004). Neural arch load-bearing in old and degenerated spines. *Journal of Biomechanics, 37*(2), 197-204. doi:10.1016/S0021-9290(03)00308-7

Pool, J., Ostelo, R., Hoving, J., Bouter, L., & de Vet, H. (2007). Minimal clinically important change of the Neck Disability Index and the Numerical Rating Scale for patients with neck pain. *Spine, 32*(26), 3047-3051. doi:10.1097/BRS.0b013e31815cf75b

Portney, L., & Watkins, M. (2009). *Foundations of clinical research applications to practice* (3 ed.). New Jersey: Pearson Prentice Hall.

Potvin, J., Norman, R., & McGill, S. (1991). Reduction in anterior shear forces on the L4L5 disc by the lumbar musculature. *Clinical Biomechanics, 6*(2), 88-96. doi:org/10.1016/0268-0033(91)90005-B

Przybyla, A. (2005). *Biomechanics of the cervical spine.* (Doctoral), University of Bristol, Bristol. (uk.bl.ethos.417643)

Puhan, M., Frey, M., Büchi, S., & Schünemann, H. (2008). The minimal important difference of the Hospital Anxiety and Depression Scale in patients with chronic obstructive pulmonary disease. *Health & Quality of Life Outcomes, 6*(1), 46. doi:10.1186/1477-7525-6-46

Quartana, P., Wickwire, E., Klick, B., Grace, E., & Smith, M. (2010). Naturalistic changes in insomnia symptoms and pain in temporomandibular joint disorder: A cross-lagged panel analysis. *Pain, 149*(2), 325-331.

Radebold, A., Cholewicki, J., Panjabi, M., & Patel, T. (2000). Muscle response pattern to sudden trunk loading in healthy individuals and in patients with chronic low back pain. *Spine, 25*(8), 947-954.

Radwan, A., Fess, P., James, D., Murphy, J., Myers, J., Rooney, M., . . . Torii, A. (2015). Effect of different mattress designs on promoting sleep quality, pain reduction, and spinal alignment in adults with or without back pain: Systematic review of controlled trials. *Sleep Health, 1*(4), 257-267. doi:org/10.1016/j.sleh.2015.08.001

Ramieri, A., Domenicucci, M., Miscusi, M., & Costanzo, G. (2015). Functional anatomy and biomechanics of the cervical spine. In P. Menchetti (Ed.), *Cervical Spine: Minimally invasive and open surgery* (pp. 11-25). Cham: Springer International Publishing.

Ravesloot, M., van Maanen, J., Dun, L., & de Vries, N. (2013). The undervalued potential of positional therapy in position-dependent snoring and obstructive sleep apnea: A review of the literature. *Sleep and Breathing, 17*(1), 39-49.

Ray, J., & Tooms, R. (1992). *Spinal configurations as associated with lower back pains while resting on various sleep ware in supine and fetal positions.* Paper presented at the Winter Annual Meeting of the American Society of Mechanical Engineers, New York, USA.

Raymann, R., Swaab, D., & Van Someren, E. (2007). Skin temperature and sleep-onset latency: Changes with age and insomnia. *Physiology and Behavior, 90*(2-3), 257-266. doi:10.1016/j.physbeh.2006.09.008

Rebelo, F., Filgueiras, E., & Soares, M. (2011). Behavior video: A methodology and tool to measure human behavior; examples in product evaluation. *Human Factors and Ergonomics in Consumer Product Design: Methods and Techniques*, 320.

Reeves, B., Deeks, J., Higgins, J., & Wells, G. (2008). Including non-randomized studies. In J. Higgins & S. Green (Eds.), *Cochrane handbook for systematic reviews of interventions*. West Sussex England: Wiley Blackwell.

Rekola, K., Keinänen-Kiukaanniemi, S., & Takala, J. (1993). Use of primary health services in sparsely populated country districts by patients with musculoskeletal symptoms: Consultations with a physician. *Journal of Epidemiology & Community Health, 47*, 153-157. doi:10.1136/jech.47.2.153

Rempel, D., Dahlin, L., & Lundborg, G. (1999). Pathophysiology of nerve compression syndromes: Response of peripheral nerves to loading. *Journal of Bone & Joint Surgery, 81*(11), 1600-1610.

Rohlmann, A., Petersen, R., Schwachmeyer, V., Graichen, F., & Bergmann, G. (2012). Spinal loads during position changes. *Clinical Biomechanics, 27*(8), 754-758. doi:10.1016/j.clinbiomech.2012.04.006

Rohmert, W., & Mainzer, J. (1986). *Influence parameters and assessment methods for evaluating body postures*. London: Taylor & Francis.

Romeijn, N., Raymann, R., Møst, E., Lindert, B., Meijden, W., Fronczek, R., . . . Someren, E. (2012). Sleep, vigilance and thermosensitivity. *European Journal of Physiology, 463*(1), 169-176. doi:10.1007/s00424-011-1042-2

Rubin, D. (2007). Epidemiology and risk factors for spine pain. *Neurologic Clinics, 25*(2), 353-371.

Runciman, W., Hunt, T., Hannaford, N., Hibbert, P., Westbrook, J., Coiera, E., . . . Braithwaite, J. (2012). CareTrack: Assessing the appropriateness of health care delivery in Australia. *Medical Journal of Australia, 197*, 100-105. doi:10.5694/mja12.10510

Russell, I., Mease, P., Smith, T., Kajdasz, D., Wohlreich, M., Detke, M., . . . Arnold, L. (2008). Efficacy and safety of duloxetine for treatment of fibromyalgia in patients with or without major depressive disorder: Results from a 6-month, randomized, double-blind, placebo-controlled, fixed-dose trial. *Pain, 136*(3), 432-444.

Russo, K., & Bianchi, M. (2016). How reliable is self-reported body position during sleep? *Journal of Clinical Sleep Medicine, 12*(1), 127.

Saifuddin, A., Braithwaite, I., White, J., Taylor, B., & Renton, P. (1998). The value of lumbar spine magnetic resonance imaging in the demonstration of anular tears. *Spine, 23*(4), 453-457.

Scannell, J., & McGill, S. (2003). Lumbar posture, should it, and can it, be modified? A study of passive tissue stiffness and lumbar position during activities of daily living. *Physical Therapy, 83*(10), 907-917. doi:10.1093/ptj/83.10.907

Schutz, F. (1941). Position of the body during sleep. *The Lancet, 241*(1), 774-775.

Schwarzer, A., Aprill, C., Derby, R., Forin, J., Kine, G., & Bogduk, N. (1994). Clinical features of patients with pain stemming from the lumbar zygapophysial joints. Is the lumbar facet syndrome a clinical entity? *Spine, 19*, 1132-1137. doi:10.1097/00007632-199405001-00006

Schwarzer, A., Wang, S., Bogduk, N., McNaught, P., & Laurent, R. (1995). Prevalence and clinical features of lumbar zygapophysial joint pain: A study in an Australian population with chronic low back pain. *Annals of the Rheumatic Diseases, 54*(2), 100-106. doi:10.1136/ard.54.2.100

Schwarzer, A., Wang, S., O'Driscoll, D., Harrington, T., Bogduk, N., & Laurent, R. (1995). The ability of computed tomography to identify a painful zygapophysial joint in patients with chronic low back pain. *Spine, 20*(8), 907-912.

Shah, J. (2009). New frontiers in the pathophysiology of myofascial pain. *Sportsphysio*(2), 20-23.

Shah, J., Danoff, J., Desai, M., Parikh, S., Nakamura, L., Phillips, T., & Gerber, L. (2008). Biochemicals associated with pain and inflammation are elevated in sites near to and remote from active myofascial trigger points. *Archives of Physical Medicine and Rehabilitation, 89*(1), 16-23.

Shah, J., & Gilliams, E. (2008). Uncovering the biochemical milieu of myofascial trigger points using in vivo microdialysis: An application of muscle pain concepts to myofascial pain syndrome. *Journal of Bodywork and Movement Therapies, 12*, 371-384.

Shan, X., Ning, X., Chen, Z., Ding, M., Shi, W., & Yang, S. (2013). Low back pain development response to sustained trunk axial twisting. *European Spine Journal, 22*, 1972-1978. doi:10.1007/s00586-013-2784-7

Sharma, M., Langrana, N., & Rodriguez, J. (1995). Role of ligaments and facets in lumbar spinal stability. *Spine, 20*(8), 887-900.

Shaw, I., Lavigne, G., Mayer, P., & Choinière, M. (2005). Acute intravenous administration of morphine perturbs sleep architecture in healthy pain-free young adults: A preliminary study. *Sleep, 28*(6), 677-682. doi:10.1093/sleep/28.6.677

Sherman, K., Cherkin, D., Erro, J., Miglioretti, D., & Deyo, R. (2005). Comparing yoga, exercise, and a self-care book for chronic low back pain: A randomized, controlled trial. *Annals of Internal Medicine, 143*(12), 849-856. doi:10.7326/0003-4819-143-12-200512200-00003

Shields, N., Capper, J., Polak, T., & Taylor, N. (2006). Are cervical pillows effective in reducing neck pain?*34*(1), 3-9. Retrieved from http://cochranelibrary-wiley.com/o/cochrane/cldare/articles/DARE-12006005307/frame.html

Shin, G., D'souza, C., & Liu, Y. (2009). Creep and fatigue development in the low back in static flexion. *Spine, 34*(17), 1873-1878.

Simmonds, J., & Keer, R. (2007). Hypermobility and the hypermobility syndrome. *Manual Therapy, 12*(4), 298-309.

Simpson, N., Scott-Sutherland, J., Gautam, S., Sethna, N., & Haack, M. (2018). Chronic exposure to insufficient sleep alters processes of pain habituation and sensitization. *Pain, 159*(1), 33-40.

Sivertsen, B., Lallukka, T., Petrie, K., Steingrímsdóttir, A., Stubhaug, A., & Nielsen, C. (2015). Sleep and pain sensitivity in adults. *Pain, 156*(8), 1433-1439.

Sivertsen, B., Lallukka, T., Salo, P., Pallesen, S., Hysing, M., Krokstad, S., & Øverland, S. (2014). Insomnia as a risk factor for ill health: Results from the large population ‐ based prospective HUNT Study in Norway. *Journal of Sleep Research, 23*(2), 124-132.

Skarpsno, E., Mork, P., Nilsen, T., & Holtermann, A. (2017). Sleep positions and nocturnal body movements based on free-living accelerometer recordings: Association with demographics, lifestyle, and insomnia symptoms. *Nature and science of sleep, 9*, 267-275. doi:10.2147/NSS.S145777

Smith, M., Perlis, M., Smith, M., Giles, D., & Carmody, T. (2000). Sleep quality and presleep arousal in chronic pain. *Journal of behavioral medicine, 23*(1), 1-13. doi:10.1023/A:100544471

Smith, S., & Trinder, J. (2001). Detecting insomnia: Comparison of four self‐report measures of sleep in a young adult population. *Journal of Sleep Research, 10*(3), 229-235.

Snook, S., Webster, B., McGorry, R., Fogleman, M., & McCann, K. (1998). The reduction of chronic nonspecific low back pain through the control of early morning lumbar flexion: A randomized controlled trial. *Spine, 23*(23), 2601-2607.

Solomonow, M. (2012). Neuromuscular manifestations of viscoelastic tissue degradation following high and low risk repetitive lumbar flexion. *Journal of Electromyography and Kinesiology, 22*, 155-175. doi:10.1016/j.jelekin.2011.11.008

Solomonow, M., Baratta, R., Banks, A., Freudenberger, C., & Zhou, B. (2003). Flexion relaxation response to static lumbar flexion in males and females. *Clinical Biomechanics, 18*, 273-279. doi:10.1016/S0268-0033(03)00024-X

Solomonow, M., Zhou, B., Baratta, R., & Burger, E. (2003). Biomechanics and electromyography of a cumulative lumbar disorder: Response to static flexion. *Clinical Biomechanics, 18*, 890-898. doi:10.1016/S0268-0033(03)00173-6

Solomonow, M., Zhou, B., Harris, M., Lu, Y., & Baratta, R. (1998). The ligamento‐muscular stabilizing system of the spine. *Spine, 23*(23), 2552-2562.

Solomonow, M., Zhou, B., Lu, Y., & King, K. (2012). Acute repetitive lumbar syndrome: A multi-component insight into the disorder. *Journal of Bodywork and Movement Therapies, 16*(2), 134-147. doi:10.1016/j.jbmt.2011.08.005

Sonoda, T. (1962). Studies on the strength for compression, tension and torsion of the human vertebral column. *J Kyoto Pref Med Univ, 71*, 659-702.

Spiegelhalder, K., Regen, W., Siemon, F., Kyle, S., Baglioni, C., Feige, B., . . . Riemann, D. (2015). Your place or mine? Does the sleep location matter in young couples? *Behavioral Sleep Medicine, 15*(2), 87-96.

Spinner, R., Poliakoff, M., & Tiel, R. (2002). The origin of “Saturday night palsy”? *Neurosurgery, 51*(3), 737-741.

Stam, R. (2007). PTSD and stress sensitisation: A tale of brain and body Part 1: Human studies. *Neuroscience & Biobehavioural Reviews, 31*(4), 530-557. doi:org/10.1016/j.neubiorev.2006.11.010

Stang, A. (2010). Critical evaluation of the Newcastle-Ottawa Scale for the assessment of the quality of nonrandomized studies in meta-analyses. *European Journal of Epidemiology, 25*, 603-605. doi:10.1007/s10654-010-9491-z

2016 Census QuickStats. (2016). Retrieved from https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/UCL513002

Regional population by age and sex, Australia, 2017. (2018). Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/3235.0

Steen, N., Hutchinson, A., McColl, E., Eccles, M., Hewison, J., Meadows, K., . . . Fowler, P. (1994). Development of a symptom based outcome measure for asthma. *British Medical Journal, 309*(6961), 1065.

Steffens, D., Ferreira, M., Latimer, J., Ferreira, P., Koes, B., Blyth, F., . . . Maher, C. (2015). What triggers an episode of acute low back pain? A case–crossover study. *Arthritis Care & Research, 67*(3), 403-410. doi:10.1002/acr.22533

Sterling, M., & Kenardy, J. (2008). Physical and psychological aspects of whiplash: Important considerations for primary care assessment. *Manual Therapy, 13*(2), 93-102. doi:org/10.1016/j.math.2007.11.003

Stewart, M., Maher, C., Refshauge, K., Bogduk, N., & Nicholas, M. (2007). Responsiveness of pain and disability measures for chronic whiplash. *Spine, 32*(5), 580-585.

Stewart, M., Maher, C., Refshauge, K., Herbert, R., Bogduk, N., & Nicholas, M. (2007). Randomized controlled trial of exercise for chronic whiplash-associated disorders. *Pain, 128*(1), 59-68.

Stinson, M., Porter-Armstrong, A., & Eakin, P. (2003). Pressure mapping systems: Reliability of pressure map interpretation. *Clinical Rehabilitation, 17*(5), 504-511. doi:10.1191/0269215503cr643oa

Stokes, I. (1988). Bulging of lumbar intervertebral discs: non-contacting measurements of anatomical specimens. *Clinical Spine Surgery, 1*(3), 189-193.

Stradling, R., & Laird, D. (1935). Further data on the handedness of sleep. *The Journal of Abnormal and Social Psychology, 29*(4), 462.

Stratford, P., Binkley, J., Riddle, D., & Guyatt, G. (1998). Sensitivity to change of the Roland-Morris back pain questionnaire: Part 1. *Physical Therapy, 78*(11), 1186-1196.

Stubbs, M., Harris, M., Solomonow, M., Zhou, B., Lu, Y., & Baratta, R. (1998). Ligamento-muscular protective reflex in the lumbar spine of the feline. *Journal of Electromyography and Kinesiology, 8*(4), 197-204.

Suckling, E., Koenig, E., Hoffman, B., & Brooks, C. (1957). The physiological effects of sleeping on hard or soft beds. *Human Biology, 29*(3), 274.

Tamaki, M., & Sasaki, Y. (Producer). (2016). How half our brain keeps watch when we sleep in unfamiliar places. Retrieved from https://theconversation.com/how-half-our-brain-keeps-watch-when-we-sleep-in-unfamiliar-places-57975

Tamura, T., Miyasako, S., Ogawa, M., Togawa, T., & Fujimoto, T. (1999). Assessment of bed temperature monitoring for detecting body movement during sleep: Comparison with simultaneous video image recording and actigraphy. *Medical Engineering & Physics, 21*(1), 1-8. doi:org/10.1016/S1350-4533(99)00020-X

Tang, N., Goodchild, C., Sanborn, A., Howard, J., & Salkovskis, P. (2012). Deciphering the temporal link between pain and sleep in a heterogeneous chronic pain patient sample: A multilevel daily process study. *Sleep, 35*(5), 675-687.

Taylor, J. (2018). *The cervical spine: An atlas of normal anatomy and the morbid anatomy of ageing and injuries*. Australia: Elsevier.

Teschke, K., Nicol, A., Davies, H., & Ju, S. (1999). *Whole body vibration and back disorders among motor vehicle drivers and heavy vehicle operators: A review of the scientific evidence*. Retrieved from The University of British Columbia: https://circle.ubc.ca/bitstream/id/2951/WBV_Report.pdf

Tetley, M. (2000). Instinctive sleeping and resting postures: An anthropological and zoological approach to treatment of low back and joint pain. *British Medical Journal, 321*(7276), 1616-1618.

Thomopoulos, S., & Genin, G. (2012). Tendon and ligament biomechanics. In B. A. Winkelstein (Ed.), Orthopaedic Biomechanics (2 ed., pp. 49-74). Boca Raton, FL: CRC Press. doi:10.1201/b13733-4

Tiemessen, I., Hulshof, C., & Frings-Dresen, M. (2008). Low back pain in drivers exposed to whole body vibration: Analysis of a dose–response pattern. *Occupational & Environmental Medicine, 65*(10), 667-675.

Toğrol, E., Çolak, A., Kutlay, M., Saraçoğlu, M., Akyatan, N., & Akin, O. N. (2000). Bilateral peroneal nerve palsy induced by prolonged squatting. *Military Medicine, 165*(3), 240-242.

Toroptsova, N., Benevolenskaya, L., Karyakin, A., Sergeev, I., & Erdesz, S. (1995). "Cross-sectional" study of low back pain among workers at an industrial enterprise in Russia. *Spine, 20*(3), 328-332.

Travell, J., & Simon, D. (1992). *Myofascial pain and dysfunction; The trigger point manual* (Vol. 2). Baltimore, ML: Williams & Wilkins.

Travell, J., & Simon, D. (1999). *Myofascial pain and dysfunction; The trigger point manual* (2 ed. Vol. 1). Baltimore, ML: Williams & Wilkins.

Tricco, A., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Levac, D., . . . Weeks, L. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine*. doi:10.7326/M18-0850

Turk, D., Dworkin, R., Trudeau, J., Benson, C., Biondi, D., Katz, N., & Kim, M. (2015). Validation of the Hospital Anxiety and Depression Scale in patients with acute low back pain. *The Journal of Pain, 16*(10), 1012-1021. doi:10.1016/j.jpain.2015.07.001

Urban, J., Holm, S., Maroudas, A., & Nachemson, A. (1982). Nutrition of the intervertebral disc: Effect of fluid flow on solute transport. *Clinical Orthopaedics and Related Research, 170*, 296-302.

van De Water, A., Holmes, A., & Hurley, D. (2011). Objective measurements of sleep for non-laboratory settings as alternatives to polysomnography: A systematic review. *Journal of Sleep Research, 20*(1pt2), 183-200. doi:10.1111/j.1365-2869.2009.00814.x

van Dieën, J., Cholewicki, J., & Radebold, A. (2003). Trunk muscle recruitment patterns in patients with low back pain enhance the stability of the lumbar spine. *Spine, 28*(8), 834-841.

van Maanen, J., & de Vries, N. (2014). Long-term effectiveness and compliance of positional therapy with the sleep position trainer in the treatment of positional obstructive sleep apnea syndrome. *Sleep, 37*(7), 1209-1215. doi:10.5665/sleep.3840

van Maanen, J., Richard, W., van Kesteren, E., Ravesloot, M., Laman, D., Hilgevoord, A., & de Vries, N. (2012). Evaluation of a new simple treatment for positional sleep apnoea patients. *Journal of Sleep Research, 21*(3), 322-329. doi:10.1111/j.1365-2869.2011.00974.x

van Niekerk, S., Louw, Q., & Hillier, S. (2012). The effectiveness of a chair intervention in the workplace to reduce musculoskeletal symptoms. A systematic review. *BMC Musculoskeletal Disorders, 13*(145). doi:10.1186/1471-2474-13-145

van Poppel, M., de Looze, M., Koes, B., Smid, T., & Bouter, L. (2000). Mechanisms of action of lumbar supports: A systematic review. *Spine, 25*(16), 2103-2113.

Vanderwee, K., Grypdonck, M., & Defloor, T. (2008). Alternating pressure air mattresses as prevention for pressure ulcers: A literature review. *International Journal of Nursing Studies, 45*(5), 784-801.

Verhaert, V. (2011). *Ergonomic analysis of integrated bed measurements: Towards smart sleep systems.* (Doctural), Katholieke Universiteit, Leuven. Retrieved from https://lirias.kuleuven.be/handle/123456789/320726

Verhaert, V., Druyts, H., Van Deun, D., Exadaktylos, V., Verbraecken, J., Vandekerckhove, M., . . . Vander Sloten, J. (2012). Estimating spine shape in lateral sleep positions using silhouette-derived body shape models. *International Journal of Industrial Ergonomics, 42*(5), 489-498. doi:10.1016/j.ergon.2012.08.002

Verhaert, V., Haex, B., De Wilde, T., Berckmans, D., Vandekerckhove, M., Verbraecken, J., & Sloten, J. (2011). Unobtrusive assessment of motor patterns during sleep based on mattress indentation measurements. *Information Technology in Biomedicine, 15*(5), 787-794.

Verhaert, V., Haex, B., De Wilde, T., Berckmans, D., Verbraecken, J., de Valck, E., & Vander Sloten, J. (2011). Ergonomics in bed design: The effect of spinal alignment on sleep parameters. *Ergonomics, 54*(2), 169–178. doi:10.1080/00140139.2010.538725

Verhaert, V., Haex, B., De Wilde, T., Cluydts, R., Berckmans, D., Verbraecken, J., & Vander Sloten, J. (2009, August). *Automatic posture recognition during sleep.* Paper presented at the Proceedings of 17th World Congress on Ergonomics, Beijing, China.

Verhaert, V., Van Deun, D., Verbraecken, J., Vandekerckhove, M., Exadaktylos, V., Haex, B., & Vander Sloten, J. (2013). Smart control of spinal alignment through active adjustment of mechanical bed properties during sleep. *Journal of Ambient Intelligence and Smart Environments, 5*(4), 369-380. doi:10.3233/ais-130216

Vernon, H., & Mior, S. (1991). The Neck Disability Index: A study of reliability and validity. *Journal of Manipulative & Physiological Therapeutics, 14*(7), 409-415.

Waddell, G. (2004). *The back pain revolution* (2 ed.). Edinburgh: Churchill Livingstone.

Ware, J., & Sherbourne, C. (1992). The MOS 36-item short-form health survey (SF-36). Conceptual framework and item selection. *Medical Care 30*, 473 – 483.

Wasiak, R., Kim, J., & Pransky, G. (2006). Work disability and costs caused by recurrence of low back pain: Longer and more costly than in first episodes. *Spine, 31*, 219-225. doi:10.1097/01.brs.0000194774.85971.df

Waugh, A., & Hill, S. (2009). Body shape distortion: Promoting postural care at night. *Learning Disability Practice, 12*, 25-29.

Webb, J., Broughton, R., McSweeney, T., & Park, W. (1976). Hidden flexion injury of the cervical spine. *The Journal of Bone and Joint Surgery. (Br.), 58*(3), 322-327.

Webb, R., Brammah, T., Lunt, M., Urwin, M., Allison, T., & Symmons, D. (2003). Prevalence and predictors of intense, chronic, and disabling neck and back pain in the UK general population. *Spine, 28*(11), 1195-1202.

Weller, E. (1979). Cervical syndrome and correct position during sleep. *Manuelle Medizin, 17*(4), 64-66.

Wells, G., Li, T., Maxwell, L., MacLean, R., & Tugwell, P. (2007). Determining the minimal clinically important differences in activity, fatigue, and sleep quality in patients with rheumatoid arthritis. *The Journal of Rheumatology, 34*(2), 280-289.

Wen, N., Lavaste, F., Santin, J., & Lassau, J. (1993). Three-dimensional biomechanical properties of the human cervical spine in vitro. *European Spine Journal, 2*(1), 2-11.

Werner, C., Ossendorf, C., Meyer, D., Blumenthal, S., & Gerber, C. (2010). Subacromial pressures vary with simulated sleep positions. *Journal of Shoulder & Elbow Surgery, 19*(7), 989-993.

White, A., & Panjabi, M. (1978). *Clinical biomechanics of the spine* (Vol. 2). Philadelphia: J B Lippincott.

White, A., & Panjabi, M. (1990). *Clinical biomechanics of the spine*. Philadelphia: J B Lippincott.

Willemen, T., Van Deun, D., Verhaert, V., Pirrera, S., Exadaktylos, V., Verbraecken, J., . . . Sloten, J. (2012). Automatic sleep stage classification based on easy to register signals as a validation tool for ergonomic steering in smart bedding systems. *Work: A Journal of Prevention, Assessment & Rehabilitation, 41*(Supplement 1), 1985-1989. doi:10.3233/WOR-2012-0419-1985

Williams, M., Hawley, J., McKenzie, R., & van Wijmen, P. (1991). A comparison of the effects of two sitting postures on back and referred pain. *Spine, 16*(10), 1185-1191.

Wing, P., Tsang, I., Gagnon, F., Susak, L., & Gagnon, R. (1992). Diurnal changes in the profile shape and range of motion of the back. *Spine, 17*(7), 761-766.

Xiao, C., Mou, C., & Zhou, X. (2019). Effect of mindfulness meditation training on anxiety, depression and sleep quality in perimenopausal women. *39*, 998-1002. doi:10.12122/j.issn.1673-4254.2019.08.19

Xie, L., Kang, H., Xu, Q., Chen, M., Liao, Y., Thiyagarajan, M., . . . Iliff, J. (2013). Sleep drives metabolite clearance from the adult brain. *Science, 342*(6156), 373-377. doi:10.1126/science.1241224

Yahia, L., Audet, J., & Drouin, G. (1991). Rheological properties of the human lumbar spine ligaments. *Journal of Biomed Engineering, 13*, 399-406. doi:10.1016/0141-5425(91)90021-X

Yamashita, T., Cavanaugh, J., El-Bohy, A., Getchell, T., & King, A. (1990). Mechanosensitive afferent units in the lumbar facet joint. *The Journal of Bone and Joint Surgery (Am.), 72*(6), 865-870.

Yang, H., & Haldeman, S. (2016). Behavior-related factors associated with low back pain in the US adult population. *Spine*(1528-1159 (Electronic)).
Yang, J., Fu, X., Liao, X., & Li, Y. (2019). Association of problematic smartphone use with poor sleep quality, depression, and anxiety: A systematic review and meta-analysis. *Psychiatry Research*, 112686. doi:10.1016/j.psychres.2019.112686
Yang, K., & King, A. (1984). Mechanism of facet load transmission as a hypothesis for low-back pain. *Spine, 9*(6), 557-565.
Yang, M., Morin, C., Schaefer, K., & Wallenstein, G. (2009). Interpreting score differences in the Insomnia Severity Index: Using health-related outcomes to define the minimally important difference. *Curr Med Res Opin, 10*, 2487-2489. doi:10.1185/03007990903167415.
Yim, J. (2015). Optimal pillow conditions for high-quality sleep: A theoretical review. *Indian Journal of Science and Technology, 8*, 135.
Yu, C. (2018). Why is self-report of sleep position sometimes unreliable? *Sleep and Hypnosis, 20*, 105-113. doi:10.5350/Sleep.Hypn.2017.19.0140
Zenian, J. (2010). Sleep position and shoulder pain. *Med Hypotheses, 74*(4), 639-643. doi:10.1016/j.mehy.2009.11.013
Zigmond, A., & Snaith, R. (1983). The Hospital Anxiety and Depression Scale. *Acta Psychiatrica Scandinavica, 67*(6), 361-370.

Appendix 1. Ethics Approval

Curtin University

Memorandum

To	Doug Cary, c/- A/Prof K Briffa, School of Physiotherapy
From	A/Prof Helen Slater, Coordinator Ethics, School of Physiotherapy
Subject	Protocol Extension Approval **PT0169**
Date	18 January 2012
Copy	Graduate Studies Officer, Faculty of Health Sciences

Office of Research and Development

Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL : hrec@curtin.edu.au

Thank you for keeping us informed of the progress of your research. The Human Research Ethics Committee acknowledges receipt of your Form B report requesting renewal for the project *"Accuracy of self report sleep postures in habitual environment."* Your application has been ***approved***.

Approval for this project remains until 18 January 2013

Your approval number remains **PT0169** please quote this number in any further correspondence regarding this project.

Thank you.

[redacted]

Assoc Professor Helen Slater
Ethics Coordinator
School of Physiotherapy

Appendix 2. Manuscript: Examining Relationships between Sleep Posture and Waking Morning Spinal Symptoms

Cary et al., J Sleep Disor: Treat Care 2016, 5:2
http://dx.doi.org/10.4172/2325-9639.1000173

Journal of Sleep Disorders: Treatment & Care

Research Article | A SCITECHNOL JOURNAL

Examining the Relationship between Sleep Posture and Morning Spinal Symptoms in the Habitual Environment Using Infrared Cameras

Cary D[1*], Collinson R[1], Sterling M[2] and Briffa NK[1]

Abstract

Introduction: Sleeping is generally considered a period for rest and recovery, however some people wake with spinal symptoms not present on going to sleep and seek treatment. It has been clinically postulated that some sleeping postures, especially those involving sustained end range rotation or extension, can provoke pain sensitive spinal tissues. While sleep research generally has blossomed, little attention has been paid to the physical effects of nocturnal posture on waking spinal symptoms. Furthermore, sleep research is generally conducted in high technology sleep laboratories that are expensive to operate and usually only accessible in metropolitan centers limiting availability to a broader population. We aimed to develop a recording protocol that was low cost, unobtrusive and portable, enabling sleep posture assessment to occur in a person's habitual environment.

Method: Fifteen participants were recruited by word of mouth. Participants completed a Pre-Sleep Questionnaire. Two infrared cameras (placed overhead and foot end of bed) plus associated recording equipment were installed in their habitual sleeping area. One camera recorded continuously, the other camera was activated by motion detection. Recordings occurred over two consecutive nights, commencing automatically at 2000hrs and stopping at 0800hrs. Four sleeping postures were defined; supine, prone, supported sidelying, where the spine is neutral and ¾ sidelying, where the spine is rotated and extended. Recordings were viewed, posture classified and the time spent in each posture calculated. Time spent in each posture for night one and night two was analyzed to determine the presence of a first night effect.

Results: The protocol was effective in capturing good quality video data. Utilising motion detection reduced analysis time by 50%. The classification system had high intra-rater reliability for all four postures (ICC > 0.91). No first night effect was detected. Participants' self-report was accurate for the proportion of the night spent in supine (ICC=0.7 95% CI 0.32 to 0.89) but not for the other three postures (ICC < 0.32 p ≤ 0.17). However when combining the two sidelying postures, self-report was accurate (ICC=0.57; 95%CI 0.10 to 0.83; p=0.01). There were no significant relationships found between the four postures and morning spinal symptoms.

Conclusion: The protocol tested provided a low cost, reliable, unobtrusive and portable method to assess sleep posture in the habitual environment that should be suitable for clinical and research purposes.

Keywords: Sleep; Posture; Self-report; Morning symptoms; Infrared camera; Habitual environment

Introduction

Sleeping is generally considered a period for rest and recovery [1,2] however some people wake with spinal symptoms not present on going to sleep [3-6]. Yet in the past 80 years, research examining sleep has focused on the electrophysiological nature of sleep, with little emphasis placed on the physical effects of posture on sleep quality [7].

A review of the recent sleep literature, with an emphasis on sleep posture reveals the majority of research is laboratory-based and primarily focused on sleep pathologies (insomnia, obstructive sleep apnea, sudden infant death syndrome) [8-11], ulcer prevention [12] and design of sleep systems (base, mattress, pillow) [13-16]. Assessment techniques using technology to measure posture include pressure mattress indentation [12,13,17,18] , actigraphy [11] static charged beds [19], thermal imaging [20], camera and videography [21-23]. These methods all have limitations. In regards to pressure mattress indentation technology, thermal imaging and static charged beds, the limitation relates to availability and cost. Actigraphy is commonly used in sleep research because it is relatively inexpensive, convenient and portable [11]. While useful for measuring movement, it does not measure posture. Videography has been used, but traditionally as an axillary channel, capturing images only in one dimension during polysomnography (PSG) and while posture is noted, intermediate postures (described later and illustrated in Appendix 1) were not detailed. Concerns have been reported in regards to privacy, quality of image and data storage. With a combination of low ambient light and low camera resolution the resultant image quality is typically described as poor [24]. Non-technological research designs have used self-report questionnaires to measure sleep posture [4,25,26]. Some have used validated methods [25] while others have not [4,26]. The validated study found self-report to be accurate for the primary sleep postures of supine, sidelying and prone, but did not report any reliability data [25]. For postures described as intermediate postures, self-report has not been examined [27].

While daytime posture has been extensively examined as a contributor to spinal symptoms, little research has examined sleep posture as a possible contributor to night or early morning spinal symptoms. Spinal tissue irritation associated with sleep postures could occur through compression, shear or torsion loads. When a constant load is applied to collagenous tissues like cartilage, ligament and capsule, movement beyond the normal range is called 'creep'. After creep has occurred and load is subsequently removed, collagen doesn't immediately return to the original position, reflecting a breaking of collagen bonds, displacement of water and proteoglycans. The period of time taken to return to normal is influenced by age (increased with increasing age), load quantity and duration [28], and previous trauma. Compression forces concentrate in the inferior

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margin of the lumbar zygoapophyseal joint (ZPJ) and increase with lordosis (extension) [29]. Spinal postures like prone and ¾ sidelying, demonstrate increased lordosis. Intermediate postures are potentially important as they involve components of spinal rotation and extension, likely to provoke pain sensitive structures [4,6,30,31]. Diagnostic blocks have confirmed ZPJs are a potent source of back pain affecting 40% of elderly, 10-15% of young injured workers and 40% of people with chronic low back pain [32,33]. Muscle fiber orientation in the lumbar spine makes the erector spinae capable of resisting shear loads [34] but this is unlikely while asleep and poor orientation of intervertebral ligaments and disc collagen fibers, means their support role is minimal. Shear load is largely attenuated via the neural arch and being bony, unlikely to deform over short periods of time [35]. Torsion loads in weight bearing are largely resisted by the ZPJ and in non-weight bearing mostly by the annulus fibrosis [36] implicating involvement of this tissue when sleeping in postures with increased torsion. It has been noted that probing the posterior annulus fibrosis in clients undergoing laminectomy with a local anesthetic and stretching evokes back pain [33,37].

A factor that may influence spinal symptoms more generally is duration of posture. It is reasonable to assume that a person sleeping in an uncomfortable position would be more frequently inclined to change their sleep posture. For this reason some researchers use the number of body shifts per night and long posture periods of immobility (LPPI), 30 minutes or longer as measures of posture stability [22,38].

Optimal spinal recovery is believed to take place when the recumbent spine is in its natural physiological shape, with a slightly flattened lumbar lordosis [39]. It has been clinically postulated that some sleeping postures could be provocative to pain sensitive spinal tissues [4,6,20,40]. It seems biologically plausible some intermediate postures and prone, with components of sustained spinal rotation and extension, could cause sustained compression and torsion stress on pain sensitive structures of the spine like the ZPJ and posterior annulus. At present there is no high level evidence to support these clinical observations.

An individual's ability to fall asleep and maintain their sleep varies enormously. Placed in a situation where the surrounds are different such as in a sleep laboratory, heightened levels of vigilance and arousal have been noted both in healthy and poor sleepers, and across a range of age groups, particularly on the first night [41]. Called the first night effect, data from this night is often excluded from analysis because of aberrant results. It has been found that the level of intervention (number of leads and attachments) relates to the severity of the first night effect. It is possible that subjects while sleeping in their habitual environment, with no leads or attachments to their bodies may not experience the first night effect. However noise from the computer cooling fans, camera red LEDs, or the knowledge of being filmed may influence their normal sleep pattern.

For the clinician treating and advising clients about the possible effects of sleeping posture on morning symptoms of spinal pain and stiffness, there is limited anecdotal evidence from observational studies and clinical textbooks, but currently there is no valid and reliable information available on which to base client advice [31,42]. A recent systematic review examining non-laboratory measurements for sleep pathology identified the need for non-invasive, low cost and user friendly objective measurements of sleep, that can be deployed in non-laboratory environments [43].

Therefore the aims of this research were to:

1. Examine the utility of new recording protocol in the habitual environment
2. Examine the accuracy of self-report of sleep postures, including intermediate postures
3. Examine the relationship between sleep posture and morning symptoms

Methods

Materials

Digital video recorder (DVR): Data capture was achieved using a DVR (Security Camera King ELITE SERIES 16 CHANNEL H2.64 www.securitycameraking.com) and stored on an internal hard drive. Industry standard H.264 image compression software was used. The DVR had its own proprietary software for playback. Settings for cameras were programed via the DVR

Cameras: To enable viewing in low light/no light situations, infrared technology (light not visual to human eye) was utilised in combination with camera lenses to record the image (Security Camera King VEILUX SVD-60IR28L2812D **www.securitycameraking.com**). The cameras had a 10 times digital zoom that enabled accurate framing of the bed area. Two cameras were used. One camera was set to activate on movement detection and record during movement plus an extra 30 seconds after movement ceased to confirm final posture. Motion detection sensitivity was set to high and applied to the total visual field of the camera using the Security Camera King software. Each movement detected constituted an event with a separate date and time stamp. The second camera was set to continuously record and had hourly time stamps. Resolution of both cameras was set to 352* 240. While both cameras had auditory recording capabilities, no sound was collected. Each camera was bolted via a mounting bracket onto a stand to enable easy disassembly and transport.

Stands and camera positioning: Two collapsible iplex stands with steel bases were constructed to enable easy disassembly, vehicle transport, and reassembly. The foot end camera was set at a height of 1.8m and the overhead camera at 2.3m (Figure 1).

Procedure

Ethics approval was provided by Human Research Ethics Committee of Curtin University (Approval Number PTO169). Fifteen participants (8 female, mean age 44 years, 87% partner sleeping) were recruited through word of mouth, information flyers in medical clinics and an article in the local paper over a period of 4 months. The author explained the procedure, and if volunteers agreed to participate, a recording date was agreed upon. There were no exclusion criteria.

On the author's arrival, participants completed a consent form and Pre-Sleep Questionnaire. See Appendix 1. Participants were asked to nominate percentage time each night spent in each of the four sleep postures and the frequency and location of morning symptoms of spine pain and stiffness that occurred during the past month. The stands and cameras were assembled in the participant's sleeping area. Power board, camera power leads and BNC cables were attached between DVR and cameras. Cables were taped or secured to minimise trip hazards. Both cameras were set to record from 2000 hours to 0800 hours.

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Figure 1: Camera Placements: Visual data collection was optimized by using two cameras that were placed so their visual orientation was nearly at right angles. One camera was placed at the foot end of the bed and the other camera directly overhead. This combination provided optimal vision and orientation to determine limb and trunk position. Using two cameras also provided data integrity if one camera failed.

Occasionally camera zoom and focus required adjustment due to varying room size and orientation of bed (Figures 2). This ensured the viewing orientation for both cameras would be synchronized, so the bed head was at the top of the picture frame and sufficient field of view was available to ensure all sides of bed were included. Participants were encouraged to perform their normal pre sleep routine in all aspects. After 2 nights the equipment was retrieved.

The video data were reviewed on the DVR, using proprietary software. Head, trunk and leg positions were noted and the overall sleep posture was categorized according to the sleep posture definitions outlined below. Each posture change was written on a data-recording sheet relative to the time stamp, accurate to the closest half minute. Times for each sleep posture interval were added up and transferred to an Excel summary spreadsheet.

Video recordings of the first night from each participant were reviewed by the same researcher several months after the initial viewing and rescored. Following preliminary review of video data it was determined that the posture definitions for prone and supine needed to be more specific to reliably classify these postures. It also became apparent there were some mathematical errors in the addition of the intervals of time spent in each posture. Therefore a spreadsheet was developed to record individual sleep posture intervals and calculate total time spent in each posture.

Sleep posture (Figure 3)

Supine: Supine was classified as when the chest was facing the ceiling. Sometimes one or both hips could be flexed, rolled or a combination of both. These combined postures were rarely held for longer than five minutes. Supine is generally considered mechanically neutral and generally doesn't result in healthy adults developing spinal pain, but is associated with restless sleep, snoring and sleep apnea [23]. It is generally a comfortable posture for people with spinal stenosis or lumbar pain [44].

Prone: Prone was defined as when the chest was facing the bed and both legs were straight. In this position the lumbar spine is in lordosis and the cervical spine in a combination of extension and rotation. If there was any degree of hip flexion, even if the participant was still chest down, it was classified as ¾ sidelying.

Avoiding a prone sleeping posture is a common clinical recommendation [45,46]. In prone, the lumbar and cervical spine lordosis (spinal extension) is increased and to enable breathing, the cervical spine is rotated. Extension reduces both central and lateral canal diameters of the lumbar spine [47] and cervical spine, potentially compressing spinal cord and peripheral nerve tissue [4,48]. Compared with supine or sidelying, prone was found to have the highest percentage of cervical related waking symptoms [49]. For clients with nocturnal exacerbation of neuropathic symptoms, Goldman recommended specific day and night postural changes (sleep in recliner chair, pillow between knees in side lining or under knees in supine) to minimize extension in a group of 11 patients with spinal stenosis and diabetes and six non-diabetic patients. In the diabetic group he found nine of the 11 patients reported moderate to excellent improvements in functional tasks, for six of these it occurred within one day. In the non-diabetic group five of the six experienced similar symptom reduction [4].

Supported Sidelying (SSL) and ¾ Sidelying (¾ SL)

In adults, sidelying is the most common sleep position [7,22,26]. Intermediate postures associated with sidelying have been acknowledged [13] and to examine the possibility they may have a different role in spinal tissue irritation, sidelying was divided into two intermediate postures; SSL and ¾ SL.

Supported sidelying was defined as the top thigh resting on the lower thigh, knee or tibia. This is a relatively supported and symmetrical posture with a flattened lordosis, which has been identified as optimal for spinal recovery [39]. With further flexion of the top hip, the top knee lowers to the mattress. This obliquity

Figure 2: Camera Orientations and Field of View: Screenshot of actual visual data showing the two cameras orientation and visible field of view for each camera.

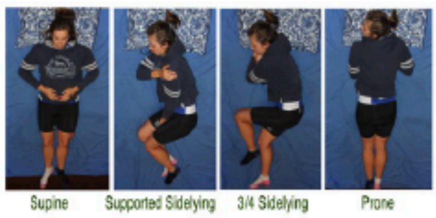

Figure 3: Sleep Posture Classifications.

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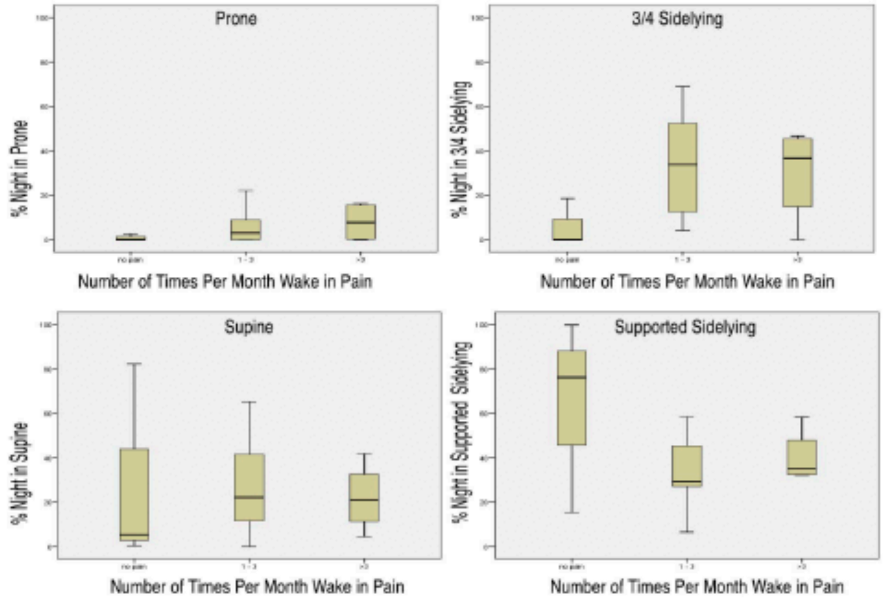

Figure 4: Comparison of time spent in each posture relative to the number of mornings waking with symptoms.

between top and lower thigh results in spinal rotation and lumbar extension, both of which are considered provocative on spinal tissues. We call this position % SL.

Data analysis

Recordings from the Night 1 were classified using the revised posture definitions in duplicate by the same investigator (DC) in random order with an interval of two weeks between duplicate analyses. Recordings from Night 2 were analysed by the same investigator. Duplicate recordings from Night 1 were used to determine intra-rater reliability using the ICC statistic reported with 95% CI. Differences in the time spent in each of the four sleep postures were compared between Nights 1 and 2 to determine whether there was a first night effect.

Minutes per night in each posture were averaged across Nights 1 and 2 and then expressed as a percentage of average total sleep time to enable comparisons with self-report sleep posture percentage data and to examine the relationship between sleep posture and morning symptoms of pain and stiffness. Associations between self-report sleep posture and average measured sleep posture in each position were examined using ICC (95%CI).

Participants reported the number of mornings per month that they woke up with spinal pain and or stiffness in the following categories: 0, 1 - 3, 4 - 6, 7 - 10, > 10 (See Appendix 1). Due to the low number of participants, these categories were collapsed into three groups: No pain, 1 - 3, more than 3 episodes of pain per month. The average proportion of the night spent in each posture was compared between the 3 groups, using the independent samples Kruskal-Wallis Test due to the small numbers in some of the groups.

Results

Utility of a new recording protocol in the habitual environment

Equipment and design: Equipment portability and setup was relatively easy across a range of different sleep environments and acceptable to participants. Set up took an average of 45 minutes. The motion detection camera picked up all changes in sleep posture, confirmed by the continuous recording camera. It took twice as long to analyze sleep posture data from the continuous camera recording (60 minutes) than from the motion detection recording (30 minutes). This time efficiency occurred firstly, because of the ability to skip from posture change event to event, rather than having to fast forward through periods without movement on the continuous recording. Secondly, when repeatedly reviewing the same event to determine the correct sleep posture, returning to the time stamp automatically created by the onset of movement, was quicker than repeated rewinding the video to the start of the movement event. We found the usage of two cameras in our protocol enabled the capturing of images from different cardinal visual planes, improving the ease of posture recognition and providing an alternative source of data in case of a camera failure.

There was no apparent first night effect of this set up in the

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participants' homes, with only small differences between Nights 1 and 2 in the time spent in each position (Table 1).

Intra-rater reliability of posture classification: Intra-rater reliability was excellent for all four postures using the revised posture classifications (Table 2).

Accuracy of self-report of sleep postures: Self-report percentages were reliably associated with video-measured percentages for supine but not for either of the sidelying postures or prone (Table 3). However, if the two sidelying postures were combined there was a significant association between the predicted percentage and the actual (measured) percentage (ICC=0.57; 95%CI 0.10 to 0.83; p=0.01).

Relationships between sleep posture and morning symptoms: The time spent in each of the sleeping postures; supine, SSL, ¾ SL and prone expressed as a percentage of the time spent asleep, did not differ significantly according to the level of morning symptoms (Independent Samples Kruskal-Wallis Test p > 0.17). However participants that spent greater periods of time in SSL, had less mornings of symptoms per month than those that slept in ¾ SL or prone (Figure 4).

Discussion

Utility of a new recording protocol in the habitual environment

Equipment and design: In this study we explored the utility and reliability of a simple, low cost, unobtrusive and portable method of measuring sleep posture in the usual sleeping environment as an alternative for posture research and clinical purposes. Typically sleep based research has been conducted in dedicated sleep laboratories. Availability, cost and artificiality of the PSG environment limit the usefulness of this option for the study of sleep posture in the broader population. Polysomnography studies, pressure mattress indentation, and thermal imaging were not directly compared to this new protocol because of the associated high cost and limited access. Commonly sleep laboratories use only a foot end camera. Using two cameras was an important element in achieving a high degree of posture visualization and data collection in the technically challenging habitual environment. When comparing utility in a habitual environment to a controlled environment, additional considerations needed to be taken into account. It was noted that social activities, pets, children and temporary illness, resulted in unplanned interruptions to a participant's normal sleeping routine. Electrical blackouts and camera malfunction did occur but the protocol was robust enough to provide adequate data collection in each situation. Given the additional time taken to arrange, meet and setup equipment, it is recommended to record an extra night; thereby providing additional data should one night be determined as 'out of the ordinary'.

Intra-rater reliability of posture classification

Prior studies of sleep posture have largely focused on the determination of three main postures; supine, prone and sidelying, in temperature controlled environments by visual analysis or self-report. Those studies using self-report of posture, did not undertake reliability studies and apart from one study using mattress indentation, none examined the reliability of intermediate sleep postures. The reliability of this new protocol to determine the two main sleep postures and two intermediate postures was very good. To maximize the reliability of this protocol we recommend the use of an electronic scoring sheet to calculate totals for each posture eliminating possibility of manual arithmetic errors.

Data collection sessions in this study involved a combination of single and couple sleeping arrangements. In an observational study of long standing partners, it was found 82% of males and 76% of the females' periods of immobility occurred synchronously [50]. As we were primarily interested in measuring sleep posture, not the number of movements per night, we considered it important to maintain as normal a sleep routine as possible and not separate couples as is common in PSG studies. If couples had separated for the recording nights, this would have created an unnatural habitual sleep environment.

Intrusiveness of equipment - first night effect

It has been noted by others that the significance of the first night effect is proportional to the recording method; the more invasive methods and the more unfamiliar the experimental environments, have a greater first time effect [41]. In our study no significant difference was found between Night 1 and Night 2 for any of the four sleep postures, indicating that the current camera setup, DVR fan noise and awareness of being filmed did not have a major effect on participants' sleeping postures in their habitual environment. Researchers using this protocol should therefore only need to record and analyse the actual number of nights required and do not need to include adaptive nights.

Accuracy of self-report of sleep postures, including intermediate postures

To date clinicians have relied on the reliability of client's self-report of sleep posture to develop appropriate health interventions. Two clinical studies investigating the relationship between posture and pain used self-report but provided no reliability data. Participants in one group had spinal stenosis [4] and the other chronic low back pain [26]. Gordon, 2004 compared 12 non clinical participants' self-report of supine, sidelying and prone to sleep center videos and reported good reliability for all postures [25]. We also found reasonable reliability for supine and sidelying, but only when the two intermediate sidelying postures were combined. However, in view of

Table 1: Difference between Nights 1 and 2 in the time (minutes) spent in each of the 4 sleep postures.

Posture	Difference (minutes)	95% Confidence Interval	p-value
Supine	15.4	- 19.8 to 50.6	0.36
Supported Sidelying	26.9	-21.9 to 75.7	0.26
¾ Sidelying	-21.3	-43.6 to 0.92	0.59
Prone	-4.1	-34.3 to 26.1	0.77

Table 2: Intra-rater reliability of duplicate classification of video recordings of sleep posture.

Posture	ICC	95% CI
Supine	0.95	0.85 to 0.98
Supported Sidelying	0.91	0.76 to 0.97
¾ Sidelying	0.97	0.91 to 0.99
Prone	0.97	0.90 to 0.99

Table 3: Reliability of Self-report estimates of night time posture compared against measured night time posture values.

Posture	ICC	95% CI	p-value
Supine	0.7	0.32 to 0.89	0.001
Supported Sidelying	0.33	-0.20 to 0.71	0.11
¾ Sidelying	0.32	-0.21 to 0.71	0.11
Prone	0.26	-0.28 to 0.67	0.17

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the plausibility that time spent in sustained rotation and extension could be provocative on spinal tissues, we wanted to determine, not only the accuracy of self-report for combined sidelying postures but also for the intermediate postures. With respect to self-report of posture, we found participants could not reliably report the proportion of the night spent in either of the sidelying postures or prone, indicating the need for an alternative and more reliable measure of sleep posture. Looking more broadly at self-report and sleep measures, participants with insomnia underestimated total sleep time, sleep latency and number of nocturnal arousals, indicating poor awareness [51]. Moreover in a classic study comparing self-reported 'poor sleepers' with 'good sleepers' using PSG, it was found that self-reported 'poor sleepers' actually slept much better than would have been expected [52].

Relationship between sleep posture and morning spinal symptoms

In accordance with others, our participants spent the greatest period of time in sidelying (after combining ¾ SL and SSL), followed by supine and the smallest period of time was spent in prone [23,53]. In adults, the most common sleep position is sidelying [7,22,26]. In an epidemiology study involving 812 phone interviews, it was found sidelying provided the most protection from waking cervical symptoms [3]. Furthermore De Koninck et al. [23] found sidelying postures with both arms and legs bent > 45 degrees, were sustained the longest. Intermediate postures associated with sidelying have been acknowledged [13] and we postulated that symmetrical postures in sidelying provide greater spinal protection than asymmetrical postures. We therefore divided the general posture of sidelying into a symmetrical non-provocative posture (SSL) and an asymmetrical provocative posture (¾ SL) [54].

We found no significant relationships between any one of the four postures and spinal symptoms. This might be due to the mismatch in time frame for these measurements. Participants were asked about their symptom frequency over the preceding month but video data was collected for only two nights. It is possible that for some, the nights recorded were not representative of typical nights. It would be beneficial in future research to include a morning after questionnaire to clarify this possibility.

Benefits of this new protocol include

- Minimal delay in implementing a sleep posture assessment as the equipment and protocol are low cost and readily available
- Sleep posture assessment can be achieved in a subject's habitual environment without medical supervision and without a first night effect
- Intermediate postures can be reliably determined from this recording protocol
- Significant cost savings can be achieved in comparison to undertaking a full PSG, either at home or in a sleep laboratory when the primary aim is to access sleep posture

Limitations of Study

In the Pre Sleep Questionnaire, self-report details were sought about what posture participants believed they were in when falling asleep and walking up. This was unable to be verified, as equipment was not used to determine sleep states. Participants were questioned about symptoms over a month, but recording of sleep posture only occurred over 2 nights.

Conclusion

A recording protocol using infrared technology that was able to reliably evaluate sleep posture has been developed. A novel feature of this protocol was the inclusion of intermediate postures, due to their postulated clinical significance. The recording protocol was low cost, portable and did not induce a first night effect. While no statistical relationship was found between individual sleep postures and morning symptoms, pilot data have been generated to inform power calculations for larger studies to investigate these hypothesized relationships.

References

1. Cabot S, Beckham N (2005) Tired of not Sleeping? Wholistic Program for a Good Night's Sleep, SCB International publisher, USA.
2. Heimanis L (2009) Sleep Better Naturally: How to Banish Insomnia and Achieve a Perfect Night's Sleep, Carlton Books ltd, UK.
3. Gordon SJ, Trott P, Grimmer KA (2002) Waking cervical pain and stiffness, headache, scapular or arm pain: Gender and age effects. Aust J Physiother 48: 9-15.
4. Goldman S (2005) Nocturnal neuropathic pain in diabetic patients may be caused by spinal stenosis. Diabet Med 22: 1763-1765.
5. Gordon S, Grimmer-Somers K, Trott P (2010) Pillow use: the behavior of cervical stiffness, headache and scapular/arm pain. J Pain Res 3: 137-145.
6. Miller R (1984) The Prone Sleeper's Spine. BOJ 16: 61-68.
7. Johnson H, Swan T, Wiegand A (1930) In what positions do healthy people sleep. JAMA 94: 2058-2062.
8. Van Maanen JP, Richard W, Van Kesteren ER, Ravesloot MJ, Laman D, et al. (2012) Evaluation of a new simple treatment for positional sleep apnoea patients. J Sleep Res 21:322-329.
9. Dwyer T, Ponsonby A, Blizzard L, Newman N, Cochrane J (1995) The contribution of changes in the prevalence of prone sleeping position to the decline in sudden infant death syndrome in Tasmania. JAMA 273: 783-789.
10. Fleming PJ, Gilbert R, Azaz Y, Berry PJ, Rudd PT, et al. (1990) Interaction between bedding and sleeping position in the sudden infant death syndrome: a population based case-control study. BMJ 301: 85-89.
11. Lichstein KL, Stone KC, Donaldson J, Nau SD, Soeffing JP, et al. (2006) Actigraphy validation with insomnia. Sleep 29: 232-239.
12. Hsia CC, Liou KJ, Aung AP, Foo V, Huang W, et al. (2009) Analysis and comparison of sleeping posture classification methods using pressure sensitive bed system. Conf Proc IEEE Eng Med Biol Soc 6131-6134.
13. Verhaert V, Haex B, De Wilde T, Berckmans D, Verbraecken J, et al. (2011) Ergonomics in bed design: the effect of spinal alignment on sleep parameters. Ergonomics 54: 169-178.
14. Gordon SJ, Grimmer-Somers K, Trott P (2009) Pillow use: the behaviour of cervical pain, sleep quality and pillow comfort in side sleepers. Man Ther 14: 671-678.
15. DeVocht JW, Wilder DG, Bandstra ER, Spratt KF (2006) Biomechanical evaluation of four different mattresses. Appl Ergon 37: 297-304.
16. Leilnahari K, Fatouraee N, Khodalotfi M, Sadeghein MA, Kashani YA (2011) Spine alignment in men during lateral sleep position: experimental study and modeling. Biomed Eng Online 10: 103.
17. Harada T, Sato T, Mori T (2001) Pressure distribution image based human motion tracking system using skeleton and surface integration model. IEEE Int Conf Robot 4: 3201-3207.
18. Abraham J, Sullivan S, Ranganathan S (2011) Low-cost and disposable pressure sensor mat for non-invasive sleep and movement monitoring applications. Conf Proc IEEE Eng Med Biol Soc 4745-4748.
19. Tamura T, Miyasako S, Ogawa M, Togawa T, Fujimoto T (1999) Assessment of bed temperature monitoring for detecting body movement during sleep: comparison with simultaneous video image recording and actigraphy. Med Eng Phys 21: 1-8.

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doi:http://dx.doi.org/10.4172/2325-9639.1000173

20. Lu L, Tamura T, Togawa T (1999) Detection of body movements during sleep by monitoring of bed temperature. Physiol Meas 20: 137-148.
21. Drakatos P, Higgins SE, Kosky CA, Muza RT, Williams AJ (2013) The Value of Video Polysomnography in the Assessment of Intermittent Obstructive Sleep Apnea. Am J Respir Crit Care Med 187: e18-20.
22. De Koninck J, Gagnon P, Lallier S (1983) Sleep positions in the young adult and their relationship with the subjective quality of sleep. Sleep 6: 52-59.
23. De Koninck J, Lorrain D, Gagnon P (1992) Sleep positions and position shifts in five age groups: an ontogenetic picture. Sleep 15:143-149.
24. Liao W, Yang C (2008) Video-based activity and movement pattern analysis in overnight sleep studies. Pattern Recognition 19th International Conference IEEE1-4.
25. Gordon S, Grimmer K, Trott P (2004) Self-reported versus recorded sleep position: an observational study. J Allied Health 2: 1-10.
26. Marin R, Cyhan T, Miklos W (2006) Sleep disturbance in patients with chronic low back pain. Am J Phys Med Rehabil 85: 430-435.
27. Verhaert V, Haex B, De Wilde T, Berckmans D, Vandekerckhove M, et al. (2011) Unobtrusive assessment of motor patterns during sleep based on mattress indentation measurements. IEEE Trans Inf Technol Biomed 15: 787-794.
28. Twomey L, Taylor J (1982) Flexion creep deformation and hysteresis in the lumbar vertebral column. Spine (Phila Pa 1976) 7: 116-122.
29. Dunlop RB, Adams MA, Hutton WC (1984) Disc space narrowing and the lumbar facet joints. J Bone Joint Surg Br 66: 706-710.
30. Bogduk N (1995) Neck pain: assessment and management in general practice. Modern Medicine in Australia. 32: 102-108.
31. McDONNELL J (1946) Sleep posture; its implications. Br J Phys Med 9: 46-52.
32. Schwarzer AC, Wang SC, Bogduk N, McNaught PJ, Laurent R (1995) Prevalence and clinical features of lumbar zygapophysial joint pain: a study in an Australian population with chronic low back pain. Ann Rheum Dis 54: 100-106.
33. Schwarzer AC, Aprill CN, Derby R, Fortin J, Kine G, et al. (1994) Clinical features of patients with pain stemming from the lumbar zygapophysial joints. Is the lumbar facet syndrome a clinical entity? Spine (Phila Pa 1976) 19: 1132-1137.
34. Potvin JR, Norman RW, McGill SM (1991) Reduction in anterior shear forces on the L4L5 disc by the lumbar musculature. Clin Biomech 6: 88-96.
35. Cyron BM, Hutton WC (1981) The behaviour of the lumbar intervertebral disc under repetitive forces. Int Orthop 5: 203-207.
36. Krismer M, Haid C, Rabl W (1996) The contribution of anulus fibers to torque resistance. Spine (Phila Pa 1976) 21: 2551-2557.
37. Adams A, Bogduk N, Burton K, Dolan P (2006) The Biomechanics of Back Pain 2nd Edn Elsevier Health Sciences, UK.
38. Lorrain D, De Koninck J (1998) Sleep position and sleep stages: evidence of their independence. Sleep 21: 335-340.
39. Dolan P1, Adams MA, Hutton WC (1988) Commonly adopted postures and their effect on the lumbar spine. Spine (Phila Pa 1976) 13: 197-201.
40. Stinson MD, Porter-Armstrong AP, Eakin PA (2003) Pressure mapping systems: reliability of pressure map interpretation. Clin Rehabil 17: 504-511.
41. Kronholm E, Alanen E, Hyyppä M (1987) Sleep movements and poor sleep in patients with non-specific somatic complaints--I. No first-night effect in poor and good sleepers. J Psychosom Res 31: 623-629.
42. McKenzie R, May S (2006) The cervical & thoracic spine: mechanical diagnosis and therapy. Raumati: Spinal Publications, New Zealand.
43. Van De Water A, Holmes A, Hurley D (2011) Objective measurements of sleep for non-laboratory settings as alternatives to polysomnography – a systematic review. J Sleep Res 20(1pt2): 183-200.
44. Boissonnault W, Fabio RP (1996) Pain profile of patients with low back pain referred to physical therapy. J Orthop Sports Phys Ther 24: 180-191.
45. Grieve G (1998) Common Vertebral Joint Problems. 2nd Edn, Churchill Livingstone, UK.
46. Kramer J (1990) Intervertebral Disc Diseases; Causes, Diagnosis, Treatment and Prophylaxis. 2nd Edn, Thieme Medical Publishers, New York.
47. Harrison DE, Cailliet R, Harrison DD, Troyanovich SJ, Harrison SO (1999) A review of biomechanics of the central nervous system--part II: spinal cord strains from postural loads. J Manipulative Physiol Ther 22: 322-332.
48. Holman AJ (2008) Positional Cervical Spinal Cord Compression and Fibromyalgia: A Novel Comorbidity with Important Diagnostic and Treatment Implications. J Pain 9: 613-622.
49. Gordon S, Grimmer K, Trott P (2007) Sleep position, age, gender, sleep quality and waking cervico-thoracic symptoms. J Allied Health 5.
50. Aaronson S, Rashed S, Biber M, Hobson J (2010) Sleeping together: a videotape look at a couples sleep. Sleep Res 9: 120.
51. Carskadon MA, Dement WC, Mitler MM, Guilleminault C, Zarcone VP, et al. (1976) Self-reports versus sleep laboratory findings in 122 drug-free subjects with complaints of chronic insomnia. Am J Psychiatry 133: 1382-1388.
52. Monroe LJ (1967) Psychological and physiological differences between good and poor sleepers. J Abnorm Psychol 72: 255-264.
53. Verhaert V, Haex B, De Wilde T, Berckmans D, Vandekerckhove, et al. (2011) Unobtrusive Assessment of Motor Patterns During Sleep Based on Mattress Indentation Measurements. IEEE Trans Inf Technol Biomed on 15: 787-794.
54. Verhaert V, Haex B, De Wilde T, Berckmans D, Vandekerckhove M, et al. (2011) Unobtrusive assessment of motor patterns during sleep based on mattress indentation measurements. IEEE Trans Inf Technol Biomed 15: 787-794.

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Appendix 3. Reliability and Validity Recording Sheet

Name: **Date:**

Instruction

In each of the three sequences; no sheet, sheet + clothes, sheet + clothes + duvet, six postures are demonstrated.

Please record the new posture in each column.

Options to choose for each posture are

1. Supine (stomach up)
2. Prone (stomach down)
3. Side lying (knees together)
4. ¼ Prone

The first series of postures are under natural light and the second sequences of postures are under infra-red light.

Light	Posture	1	2	3	4	5	6
Natural	No Sheet						
	Sheet						
	Duvet						
Infra-Red	No Sheet						
	Sheet						
	Duvet						

Appendix 4. Manuscript: Examining the Validity and Reliability of a Portable Sleep Posture Assessment Protocol

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Examining the validity and reliability of a portable sleep posture assessment protocol, using infrared cameras, under a variety of light and bed cover situations in the home environment

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Abstract.
BACKGROUND: Spinal symptoms of pain and stiffness on waking have been linked to sleep posture. Sleep posture is commonly classified as supine, side lying and prone. It is clinically postulated that sleeping postures with sustained end of range rotation and extension may influence pain sensitive spinal tissues. However, the lack of a valid and reliable method of assessing sleep posture, means clinicians are unable to provide corrective advice based upon evidenced based research.
OBJECTIVE: To determine the validity and reliability of a sleep posture recording protocol in the home environment.
METHOD: Twenty health professionals viewed a pre-recorded video recording of randomized sleep postures under natural and infrared light situations, with a variety of bed coverings, to represent the habitual environment. Sleep postures were classified into six categories including two intermediate postures (supported side lying and provocative side lying). Viewing was repeated after two days.
RESULTS: Intra-and inter-rater reliability were excellent; Cohen's Kappa = .93 (95% CI 0.80 to 1.0) and Fleiss Kappa = 0.83 (95% CI 0.82 to 0.84) respectively. Validity, determined as concordance between the health professionals' classifications and the known postures, was also excellent Cohen's Kappa = .91 (95% CI 0.77 to 1.0).
CONCLUSIONS: Reliable and valid assessment of sleep posture, including intermediate postures, could be achieved using low cost, portable, infrared video recording equipment, under a variety of lighting conditions and a variety of bed cover situations typical of the home environment.

keywords: Ergonomics, spine pain, spine stiffness, sleep posture assessment, habitual environment, sleep posture classification, intermediate sleep postures

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1. Background

Daytime posture is considered a contributor to spinal symptoms [1], while sleep is generally considered a period for rest and recovery for workers [2]. It has been identified, that high quality sleep is critical for workers' recovery [3]. However, some people wake with spinal symptoms, like pain, stiffness and paraesthesia, not present when going to sleep which impact on their sleep quality [4–6]. Self-reported sleep disturbances are associated with reduced performance and increased healthcare costs [7], increased risk of occupational injury [8], cause-specific work disability and delayed return to work [9].

It has been clinically postulated, that some sleeping postures involving sustained end range spinal rotation and or extension, may provoke pain sensitive spinal tissues [4, 10] and therefore affect quality of sleep. At present, there is no high-level evidence to support these clinical observations, possibly due to a lack of appropriate techniques to measure sleep posture. Current sleep posture measurement techniques can be divided into non-technological and technological.

Non-technological research designs have used self-report or questionnaires to measure sleep posture, however most of these have not been validated against a gold standard of measuring sleep posture [4, 11, 12], while others have queried the reliability of self-report [13, 14]. With a small group of healthy participants [15], researchers validated their self-report questionnaire with a single infrared [IR] camera recording, using sleep posture criteria previously described [16]. They found self-report was accurate for the sleep postures of supine, side lying, and prone; however, no validity or reliability data were presented for their IR video classification system [15]. Self-report has also been studied in patient populations. Researchers explored the relationship between sleep posture (supine, side lying and prone) and primary open angle glaucoma, in which self-report was compared to continuous posture monitoring using an Embletta X10 sleep monitor [17]. In another study, researchers explored the relationship between sleep posture and OSA [13]. In the former, self-report of sleep posture was significantly associated with sleep posture [$p = .03$], while it was not found to be reliable in the latter, and recommendations were made to not solely rely on self-report. Self-report has not been examined for intermediate postures [18], the importance and clinical relevance of which are discussed later.

Technological assessment of sleep posture includes pressure mattress indentation [19, 20], capacitance sensing [21], thermal imaging [22], camera and videography [23, 24] and actigraphy [25]. Utility of the first three methods is limited by availability and cost. Researchers use IR light videography as part of polysomnography [23, 24], to determine sleep posture [6, 26, 27] or to compare posture with other equipment [28]. Infrared eliminates the need for white light, which is known to interfere with sleeping, but using the IR light band in total darkness creates non-uniformities (overexposure in the centre) [29]. Furthermore, examples of IR image capture in the prior paragraph, did so in only one dimension, limiting accuracy due to variable bed covers, light reflection and shallow depth of field. Concerns in association with videography have previously been reported in regards to privacy, quality of image and data storage [28], but with modern equipment, image quality and data storage, these are no longer significant limitations. Actigraphy is inexpensive and commonly used to measure movement [25], however it does not measure posture. A systematic review identified the need for non-invasive, low cost and user friendly objective measurements of sleep, that can be deployed into non-laboratory environments [30]. While some researchers have utilised self-report and IR imaging in institutional dormitories [6, 31], we are not aware of these methods being used in home environments to measure sleep posture.

Sleep posture has been previously classified in different ways, but is most commonly classified into supine, side lying and prone[14–16]. In this three-level classification, supine is where the chest faces the roof, prone is when the chest faces the floor, and all other postures were considered side lying. As a result, side lying is the most commonly classified sleep posture in adults [15, 31, 32]. However, there are several variations contained within the classification of side lying [33–35], termed intermediate postures. Prior researchers scored sleep posture images, obtained from a single IR video camera of healthy participants in a sleep laboratory and noted that intermediate side lying postures occurred. Their approach was to sub-classify these side lying postures based upon pelvic orientation [26]. However, no reliability or validity data for the manual scoring of video images were provided.

Another method used to sub-classify side lying sleep postures, is based on plausible spinal tissue load. When considering whether a sleep posture could

Fig. 1. Sleep Posture Classification. Historically sleep postures have been classified into four groups, supine, prone, and side lying. Adults spend the greatest period of time sleeping in side lying, however there is a wide variety of side lying postures that involve varying degrees of spine rotation and extension. It is anecdotally acknowledged that sleep positions involving spinal rotation and extension, increase spinal tissue load and contribute to waking spinal symptoms. Therefore, for clinical utility, it would be of benefit to sub-classify the broader side lying posture into specific intermediate postures, based upon the associated biomechanical load. For this reason, we identified the posture of supported side lying [SSL] in which there is minimal spinal rotation or extension and provocative side lying [PSL] in which there is a combination of spine rotation and extension.

Fig. 2. Camera Setup. Sleep imaging initially was provided with hand drawings, then photographs and currently using video captured infrared images. The most common current setting is in a sleep research laboratory associated with polysomnography, in which video footage is obtained from one viewing angle, usually the foot end of the bed. Determining the positioning of a three-dimensional object like the leg, in relation to the other leg or trunk can be difficult when viewed from one angle only. For this reason, we trialled several dual camera setups. We found that having two cameras, with different viewing angles [one overhead and one at the foot end of the bed], provided good depth perception on viewing, relative ease of setup and provided backup data collection, in the advent of one camera failing.

Consent for the publication of this study and any additional related information was provided by the model involved in this study.

The recorded video was then imported into video editing software where a short training section was added. This consisted of a picture of each of the

Fig. 3. Visual Quality and Viewing Angles. A criticism of infrared captured images has been picture quality and the subsequent inability to determine sleep posture. For this reason, we selected cameras that provided enough resolution to provide high quality images to discern sleep posture. Furthermore, because pictures have no depth perception, we chose camera alignment that assisted in the determination of relative limb and trunk placement. This picture shows the model in the supported side lying posture, covered by a sheet, from the foot end camera and the overhead camera under infrared light.

sleep postures, with superimposed explanatory text describing the key feature of the sleep posture (supine, SSL, PSL and prone) (See Fig. 4). Total video time was nearly ten minutes, including the training section. The video was uploaded to YouTube and 20 health care professionals were recruited by personal invitation to participate using personalized links. Informed consent was sought and granted by each health care professional. The professionals viewed the video on two separate occasions, with at least a two-day interval between viewings. After each video viewing, the professionals were asked to identify each of the 36 sleep postures as supine, SSL (right and left were combined), PSL (right and left were combined)or prone and email their recording sheet to the researcher.

2.3. Data analysis

Inter-rater reliability was determined using Fleiss Kappa comparing the concordance of classifications

Fig. 4. Screen-shot of Video's Training Section. In the Training section of the video, screen shots of each sleep posture were included, highlighting to raters how to determine each of the different sleep postures. Figure 4. demonstrates the provocative side lying sleep posture, under the condition of natural light and no bed covers.

made by the 20 health professionals during their first viewing of the recorded postures under different lighting and bed conditions. Intra-rater reliability was analysed using Cohen's Kappa, comparing the classifications made by each professional during their first and second viewings of the recorded postures. Validity was determined using Cohen's Kappa comparing the classification of each of the 20 professionals during their first viewing of the video against the known posture of the model.

3. Results

Twenty health professionals (18 physiotherapists, 2 chiropractors; 12 female) with two to 42 years of clinical experience (mean 16.7, SD 12.4), viewed the YouTube recording twice.

Inter- and intra-rater reliability were excellent. Cohen's Kappa for intra-rater reliability was .93 (95% CI = .80 to 1.0) with a value of 1.0 for 25% of the health professionals and Fleiss Kappa for inter-rater reliability was 0.83 (95% CI = .82 to.84).

coverings commonly found in a home environment. Further, it has demonstrated that health professionals with varying levels of clinical experience can accurately interpret the results. This protocol now provides the opportunity for sleep posture assessment to be performed in a client's home environment and not a sleep laboratory, with the potential to identify relationships between sleep postures, spinal symptoms and other medical conditions.

List of abbreviations

IR: Infra-red,
SSL: Supported side lying,
PSL: Provocative side lying

Conflict of interest

The authors declare that they have no competing interests.

Funding

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References

[1] Norman R, Wells R, Neumann P, Frank J, Shannon H, Kerr M. Comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. Clinical Biomechanics. 1998;13(8):561-73.

[2] McCanlies E, Slaven J, Smith L, Andrew M, Charles L, Burchfiel C, et al. Metabolic syndrome and sleep duration in police officers. Work. 2012;43(2):133-9.

[3] Silva-Costa A, Griep R, Fischer F, Rotenberg L. Need for recovery from work and sleep-related complaints among nursing professionals. Work. 2012;41(Supplement 1):3726-31.

[4] Goldman S. Nocturnal neuropathic pain in diabetic patients may be caused by spinal stenosis. Diabet Medicine. 2005;22:1763-5.

[5] Gordon S, Grimmer K, Trott P. Understanding sleep quality and waking cervico-thoracic symptoms. Internet Journal of Allied Health Sciences and Practice. 2007;5:1-12.

[6] Desouzart G, Vilar E, Melo F, Matos R, editors. Human bed interaction: A methodology and tool to measure postural behavior during sleep of the air force military. 3rd International Conference on Design, User Experience, and Usability; 2014 June; Heraklion, Greece.

[7] Hui S, Grandner M. Trouble Sleeping Associated with Lower Work Performance and Greater Healthcare Costs: Longitudinal Data from Kansas State Employee Wellness Program. Journal of occupational and environmental medicine/American College of Occupational and Environmental Medicine. 2015;57(10):1031.

[8] Melamed S, Oksenberg A. Excessive daytime sleepiness and risk of occupational injuries in non-shift daytime workers. Sleep. 2002;25(3):315-22.

[9] Salo P, Oksanen T, Sivertsen B, Hall M, Pentti J, Virtanen M, et al. Sleep disturbances as a predictor of cause-specific work disability and delayed return to work. Sleep. 2010;33(10):1323-31.

[10] Cary D, Collinson R, Sterling M, Briffa K. Do we know our sleep posture and does sleep posture influence spinal symtpoms? Sleep and Bilogical Rhythms. 2014;12:1-85.

[11] Noll M, Candotti C, Rosa B, Valle M, Antoniolli A, Vieira A, et al. High prevalence of inadequate sitting and sleeping postures: A three-year prospective study of adolescents. Scientific Reports. 2017;7:14929.

[12] Desouzart G, Matos R, Melo F, Filgueiras E. Effects of sleeping position on back pain in physically active seniors: A controlled pilot study. Work. 2016;53:235-40.

[13] Russo K, Bianchi M. How reliable is self-reported body position during sleep? Journal of clinical sleep medicine: JCSM: Official publication of the American Academy of Sleep Medicine. 2016;12(1):127.

[14] Yu C. Why is self-report of sleep position sometimes unreliable? Sleep and Hypnosis. 2018;20:105-13.

[15] Gordon S, Grimmer K, Trott P. Self reported versus recorded sleep position: An observational study. The Internet Journal of Allied Health Science and Practice. 2004; 2:1-10.

[16] Dzvonik M, Kripke D, Klauber M, Ancoli-Israel S. Body position changes and periodic movements in sleep. Sleep. 1986;9(4):484-91.

[17] Kaplowitz K, Blizzard S, Blizzard D, Nwogu E, Hamill C, Weinreb R, et al. Time Spent in Lateral Sleep Position and Asymmetry in Glaucoma. Investigative Ophthalmology & Visual Science. 2015;56(6):3869-74.

[18] Verhaert V, Haex B, De Wilde T, Berckmans D, Vandekerckhove M, Verbraecken J, et al. Unobtrusive assessment of motor patterns during sleep based on mattress indentation measurements. Information Technology in Biomedicine. 2011;15(5):787-94.

[19] Deun D, Verhaert V, Willemen T, Wuyts J, Verbraecken J, Exadaktylos V, et al. Biomechanics-based active control of bedding support properties and its influence on sleep. Work. 2012;41(Supplement 1):1274-80.

[20] Pino EJ, Dorner De la Paz A, Aqueveque P, Chavez JA, Moran AA. Contact pressure monitoring device for sleep studies. Conference proceedings : Annual International Conference of the IEEE Engineering in Medicine and Biology Society IEEE Engineering in Medicine and Biology Society Conference. 2013;2013:4160-3.

[21] Rus S, Grosse-Puppendahl T, Kuijper A. Evaluating the recognition of bed postures using mutual capacitance sensing. Journal of Ambient Intelligence and Smart Environments. 2017;9(1):113-27.

[22] Lu L, Tamura T, Togawa T. Detection of body movements during sleep by monitoring of bed temperature. Physiological Measurement. 1999;20(2):137.

[23] De Koninck J, Lorrain D, Gagnon P. Sleep positions and position shifts in five age groups: An ontogenetic picture. Sleep. 1992;15:143-9.
[24] Drakatos P, Higgins S, Kosky C, Muza R, Williams A. The Value of Video Polysomnography in the Assessment of Intermittent Obstructive Sleep Apnea. American Journal of Respiratory and Critical Care Medicine. 2013;187(10):e18-20.
[25] O'Donoghue G, Fox N, Heneghan C, Hurley D. Objective and subjective assessment of sleep in chronic low back pain patients compared with healthy age and gender matched controls: A pilot study. BMC musculoskeletal disorders. 2009;10(1):122.
[26] Verhaert V, Haex B, De Wilde T, Berckmans D, Verbraecken J, de Valck E, et al. Ergonomics in bed design: The effect of spinal alignment on sleep parameters. Ergonomics. 2011;54(2):169-78.
[27] Desouzart G, Filgueiras E, Matos R. Relationship between postural reeducation technique during sleep and relaxation technique in sleep quality. Procedia Manufacturing. 2015;3:6093-100.
[28] Liao W, Yang C, editors. Video-based activity and movement pattern analysis in overnight sleep studies. Pattern Recognition, 2008 ICPR 2008 19th International Conference on; 2008: IEEE.
[29] Liao W-H, Yang C-M, editors. Video-based activity and movement pattern analysis in overnight sleep studies. Pattern Recognition, 2008 ICPR 2008 19th International Conference on; 2008: IEEE.
[30] Van De Water A, Holmes A, Hurley D. Objective measurements of sleep for non-laboratory settings as alternatives to polysomnography – a systematic review. Journal of Sleep Research. 2011;20(1pt2):183-200.
[31] Desouzart G, Filgueiras E, Melo F, Matos R, editors. Human body-sleep system interaction in residence for university students: Evaluation of interaction patterns using a system to capture video and software with observation of postural behaviors during sleep. 5th International Conference on Applied Human Factors and Ergonomics; 2014 July; Kraków, Poland.
[32] Verhaert V, Van Deun D, Verbraecken J, Vandekerckhove M, Exadaktylos V, Haex B, et al. Smart control of spinal alignment through active adjustment of mechanical bed properties during sleep. Journal of Ambient Intelligence and Smart Environments. 2013;5(4):369-80.
[33] De Koninck J, Gagnon P, Lallier S. Sleep positions in the young adult and their relationship with the subjective quality of sleep. Sleep. 1983;6(1):52-9.
[34] Hsia C, Liou K, Aung A, Foo V, Huang W, Biswas J, editors. Analysis and comparison of sleeping posture classification methods using pressure sensitive bed system. Engineering in Medicine and Biology Society; 2009: IEEE.
[35] Wai A, Foo S, Huang W, Biswas J, Hsia C, Liou K, et al. Lying Posture Classification for Pressure Ulcer Prevention. Journal of Healthcare Engineering. 2010;1(2):217-38.
[36] Cary D, Collinson R, Sterling M, Briffa K. Examining the relationship between sleep posture and morning spinal symptoms in the habitual environment using infrared cameras. Journal of Sleep Disorders: Treatment and Care. 2016;5.
[37] Gordon S, Grimmer K, Trott P. Sleep position, age, gender, sleep quality and waking cervico-thoracic symptoms. Internet Journal of Allied Health Sciences and Practice. 2007;5.
[38] Goldman S. Neurogenic Positional Pedal Neuritis. Journal of the American Podiatric Medical Association. 2003;93(3):174-84.
[39] Itasaka Y, Miyazaki S, Ishikawa K, Togawa K. The influence of sleep position and obesity on sleep apnea. Psychiatry and Clinical Neurosciences. 2000;54(3):340-1.
[40] Harvey R, Hadley N, Gill T, Beats B, Gordon P, Long D, et al. Effects of sleeping with the bed-head raised and of ranitidine in patients with severe peptic oesophagitis. The Lancet. 1987;330(8569):1200-3.
[41] Edlich R, Winters K, Woodard C, Buschbacher R, Long III W, Gebhart J, et al. Pressure ulcer prevention. Journal of long-term effects of medical implants. 2004;14(4).
[42] Hurwitz E, Randhawa K, Yu H, Côté P, Haldeman S. The Global Spine Care Initiative: A summary of the global burden of low back and neck pain studies. European Spine Journal. 2018;1-6.
[43] Bigatti S, Hernandez A, Cronan T, Rand K. Sleep disturbances in fibromyalgia syndrome: Relationship to pain and depression. Arthritis Care & Research. 2008;59(7):961-7.
[44] Simpson N, Scott-Sutherland J, Gautam S, Sethna N, Haack M. Chronic exposure to insufficient sleep alters processes of pain habituation and sensitization. Pain. 2018;159(1):33-40.

Appendix 5. Study Recruitment Strategies

Newspaper Article

Sleep study participants sought

A SLEEP postures study is being conducted in Esperance to research the relationship between sleep positions and back pain.

Specialist Musculoskeletal Physiotherapist FACP Doug Cary is conducting the study during March and April as part of his Master by Research at Curtin University.

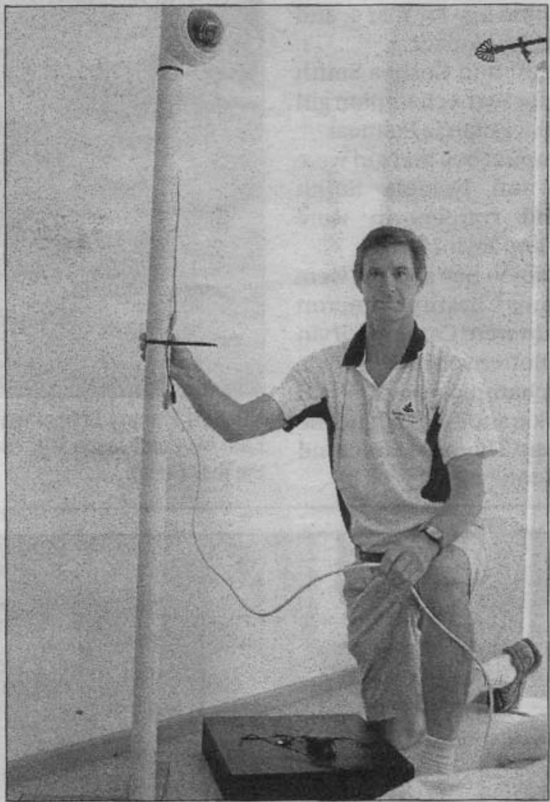
Each participant's sleep is monitored using video cameras set up in their bedroom over two nights.

Mr Cary said he was using in-house methods of assessment.

"I am trying to establish whether technology can enable us to image night-time sleep positions," he said.

"They might, in the future, permit the use of in-house sleep posture assessment methods in country areas and negate the need for people with back pain to travel to a hospital to be monitored."

Mr Cary is looking for participants between 18 and 80 years of age.



Specialist Musculoskeletal Physiotherapist FACP Doug Cary sets up a camera in a sleep study participant's bedroom.

People receiving treatment for pain management or sleep apnea, and with conditions that affect their normal sleep, such as pregnancy or shift work are unable to participate.

To register to participate, contact Esperance Physiotherapy on 9071 5055.

Radio Interviews

28/8/2014 ABC Esperance. Click here

17/9/2014 HOT FM Esperance. Click here

Press Release 9/11/2015

Local Physiotherapist Undertaking World's First Research.

Local physiotherapist Doug Cary, is conducting research in conjunction with Curtin University and Queensland University as part of his PhD, examining the relationships between sleep posture and spinal pain.

To do this they are currently recruiting people between 18 - 45 years of age in three broad categories;

1. No morning spine pain or stiffness
2. Several mornings per month of spine pain or stiffness in the neck and
3. Several mornings per month of spine pain or stiffness in the low back

"We sleep for 1/3 of our lives and yet we don't know the link between common sleep postures and spine pain" says Doug "which is a real gap in our understanding of posture and spine pain. There are volumes of research looking at sport and spine pain, work and spine pain, pregnancy and spine pain, but not sleep positions and spine pain. We aim to address this with this new research"

To achieve this, they require 30 more people to enroll in the study to ensure they have sufficient numbers to provide reliable data. "We are half way into this study and would love to have enough numbers to provide good data that can then translate into real findings to guide professionals who are providing advice all around the world" said Doug.

To be involved in this study you can contact Doug via;

Phone: 90715055

Email: douglas.cary@postgrad.curtin.edu.au

Mail/Drop by: 5 William Street

Flyer and Newspaper Advert

Can You Help?

Seeking Participants for World's First Research

30 People in 3 months

We are seeking the involvement of community members to examine the relationship between **sleep posture and spine symptoms**. For this reason we require people that have either **no pain** and people that have either **neck** or **back morning pain.**

Your Involvement

For the purpose of this study, participants must be;

- Between 18 and 45 years of age
- Able to move freely in bed (no server pain, apnea machines, sleeping medications)
- Willing to complete an online questionnaire (15-20 minutes)
- A researcher will position two cameras on stands in your bedroom, that will video your sleep posture over two consecutive nights. This is to enable calculation of the amount of time you spend in each sleep position.

All information remains confidential as per Curtin University Ethics Guidelines.

What to Do

Please contact **Doug Cary**, 5 William Street, Esperance WA 6450 or by telephoning **90715055** or by emailing douglas.cary@postgrad.curtin.edu.au. Thank you !!

Research Undertaking

Mr. Doug Cary (ID 08411419) is completing his Doctorate by Research at Curtin University; examining links between sleep posture and the human spine. This project is supervised by A/Prof. Kathy Briffa Curtin University and Prof. Michele Sterling The University of Queensland. This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number HR140/2014). The Committee is comprised of members of the public, academics, lawyers, doctors and pastoral carers. If needed, verification of approval can be obtained either by writing to the Curtin University Human Research Ethics Committee, c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.

Appendix 6. Participant Information and Consent Form

Information & Consent Form

Accuracy Of Self-Report Sleep Position In Habitual Environment

Candidate: Doug Cary

Supervisors: Associate Professor Kathy Briffa & Associate Professor Michele Sterling

Introduction

Your participation in this research study is voluntary. The purpose of this study is to determine whether people actually do sleep in the position they think they sleep in. To do this we will ask you to complete a questionnaire about your sleeping positions and compare your responses with infrared video recordings of your movements while you sleep.

We are looking at people's sleep positions in their home with their usual sleeping arrangements. To do this the researcher will install equipment (2 infrared cameras on tripods and a hard drive) in your bedroom at a convenient time for you. The machine will automatically turn on at 8.00pm and stop recording at 8.00am. Recording will be for two nights. Equipment will be collected after the second night. Prior to recording your sleep, we will ask you to complete a questionnaire (general questions and sleep positions). This will take about 20 minutes. A summary of results will be available to you after the study.

Privacy

The images collected on the video will be infrared so likeness to the participants will not be clear, however it may be possible to recognize participants. Only the investigators will view the images and stored images will be password protected, accessible only by the investigators and identified by number only. They will be securely archived at Curtin University for five years.

Contact

Should you have any queries please contact Mr. Doug Cary on 90715055

Ethical Details

The Curtin University Human Research Ethics Committee has approved this study. (Approval Number PTO169). The Committee consists of public members, academics, lawyers, doctors and pastoral carers. Its main role is to protect participants. Verification of approval can be obtained by writing to the Curtin University Human Research Ethics Committee.
Office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth 6845, telephoning 9266 9223 or emailing hrec@curtin.edu.au.

Consent Form

Accuracy Of Self-Report Sleep Position In Habitual Environment

Candidate: Doug Cary
Supervisors: Associate Professor Kathy Briffa & Associate Professor Michele Sterling

- I have read the information above.
- I am 18 years or older, and not currently receiving medical management for pain, sleep apnea or any other condition that would affect my normal sleep routine
- Any questions I have asked have been answered to my satisfaction. I agree to participate in this research but understand that I can change my mind or stop at any time.
- I understand that all information provided is treated as confidential.
- I agree to be recorded while sleeping.
- I agree that research gathered for this study may be published, provided names or any other information that may identify me is not used.
- I understand the requirements of this study and will take care of equipment while in my possession.

Participant:	Researcher:
Name ____________________	Name ____________________
Signature____________________	Researcher Signature ________________
Date ________________	

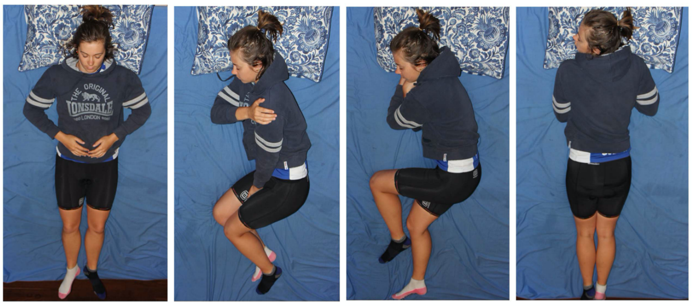
2 Participant Information and Consent Form

Appendix 7. Pre-Sleep Questionnaire

Male/Female

Age________ ID Number__________________

Please answer each question using the following pictures as references.



Supine Supported Side lying Provocative Side lying Prone

1. Which posture most closely resembles the posture you are lying in when you fall asleep?

- Supine
- R or L Supported side lying
- R or L Provocative side lying
- Prone

2. Which posture most closely resembles the posture you are lying in when you wake up?

- Supine
- R or L Supported side lying
- R or L Provocative side lying
- Prone

3. What percentage of the night do you spend in each posture?

- Supine (%)
- R or L Supported side lying (%)
- R or L Provocative side lying (%)
- Prone (%)
- TOTAL 100%

4. How many mornings a month would you wake up feeling noticeably stiff or sore?

- 0
- 1-3
- 4-6
- 7-10
- more than 10

5. If you wake up stiff or sore is it your;

- Neck
- Back
- Both
- Other ____ (please describe)

Date Video recording 1 ___________

Date Video recording 2 ___________

Appendix 8. Observation Without Light (OWL) Sheet

OWLS Recording Sheet

Date:

ID Number:

						Duration			
Clock	Head	Trunk	Legs	Classification	Duration	S	SL	3/4	P
					Start				
			Total Sleep Time (mins)						

Rounding of seconds 1-30 = lower number, 31-59 higher number

Appendix 9. Ethics Approval

Curtin University

Memorandum

To	Associate Professor Kathy Briffa, Physiotherapy
From	Professor Peter O'Leary, Chair Human Research Ethics Committee
Subject	Protocol Approval **HR 140/2014**
Date	15 July 2014
Copy	Mr Doug Cary, Physiotherapy Professor Michele Sterling Physiotherapy

Office of Research and Development
Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for providing the additional information for the project titled "*The effect of changing sleep posture in the habitual environment on spinal symptoms*". The information you have provided has satisfactorily addressed the queries raised by the Committee. Your application is now **approved.**

- You have ethics clearance to undertake the research as stated in your proposal.
- The approval number for your project is **HR 140/2014.** *Please quote this number in any future correspondence*.
- Approval of this project is for a period of four years **10-07-2014** to **10-07-2018.**
- Your approval has the following conditions:
  i) Annual progress reports on the project must be submitted to the Ethics Office.
- **It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed.**

Applicants should note the following:

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

The attached **Progress Report** should be completed and returned to the Secretary, HREC, C/- Office of Research & Development annually.

Our website https://research.curtin.edu.au/guides/ethics/non_low_risk_hrec_forms.cfm contains all other relevant forms including:

- Completion Report (to be completed when a project has ceased)
- Amendment Request (to be completed at any time changes/amendments occur)
- Adverse Event Notification Form (If a serious or unexpected adverse event occurs)

Yours sincerely

[redacted]

Professor Peter O'Leary
Chair Human Research Ethics Committee

Appendix 10. Australian New Zealand Clinical Trial Registry

Re: The effect of sleep posture on spinal symptoms

Thank you for submitting the above trial for inclusion in the Australian New Zealand Clinical Trials Registry (ANZCTR).

Web address of your trial:
http://www.ANZCTR.org.au/ACTRN12614000708651.aspx
Date submitted: 18/06/2014 4:24:52 PM
Date registered: 4/07/2014 11:17:25 AM
Registered by: Doug Cary

ANZCTR number: ACTRN12614000708651

Re: The effect of changing sleep posture on spinal symptoms

Thank you for submitting the above trial for inclusion in the Australian New Zealand Clinical Trials Registry (ANZCTR).

Web address of your trial: http://www.ANZCTR.org.au/ACTRN12614000707662.aspx
Date submitted: 18/06/2014 3:55:25 PM
Date registered: 4/07/2014 10:36:22 AM
Registered by: Doug Cary

ANZCTR number: ACTRN12614000707662

Appendix 11. Morning After Questionnaire

***1. ID Number (provided by researcher)**

***2. Video Night Number**

- 1
- 2
- 3

***3. If you woke up this morning with symptoms, where did you mostly feel them?**

- Nil
- Upper back and neck
- Mid and lower Back

***4. Please record your average spine bothersomeness, experienced this morning.**

No bothersomeness = 0	1	2	3	4	5	6	7	8	9	Worst bothersomeness = 10

***5. Please record your average spine pain, experienced in this morning.**

No pain = 0	1	2	3	4	5	6	7	8	9	Worst pain = 10

***6. Please record your average spine stiffness, experienced in the morning.**

No stiffness = 0	1	2	3	4	5	6	7	8	9	Worst stiffness = 10

***7. Please record your average quality of sleep, experienced in this morning.**

Light/Restless = 0	1	2	3	4	5	6	7	8	9	Heavy/Sound = 10

Appendix 12. Sleep Posture Recruitment Form

Sleep Posture Recruitment Form

Name ____________________________ Date _____________________

Address ____

Phone (H) ________________ (M) ____________________ Email _______________________________

This study is examining the relationship between sleep postures and spine morning symptoms.

1. Are you interested in participating? Y N
2. Are you fluent in English, both written & spoken? Y N
3. Are you between 18 and 45 years of age? Y N
4. Do you have medical conditions or use devices that prevent person from sleeping in all postures e.g. severe OA, esophageal reflux, breathing apparatus, late stage pregnancy Y N

5. Do you have medically diagnosed inflammatory conditions or unremitting pain? e.g. RA, AS, radicular pain Y N

6. Do you take prescribed hypnotic or relaxant medications? e.g. valium, soma, flexeril Y N

7. Have you been previously treated by me for spinal pain? Y N

8. Do you experience spinal pain/stiffness or bothersomeness in the morning?
N **You are eligible for the Normal group**. Okay to be a part of this group?
Y Allocate to Normal Group N Why is that? _____________________________

9. Y: Which one? P / S / B
Would you experience these 4 or more times per month, or approximately once per week?
N **You are eligible for the Normal group**. Okay to be a part of this group?
Y Allocate to Normal Group N Why is that? _____________________________

10. Y: For the purpose of this research, we grade pain/stiffness or bothersomeness on a scale from 0 to 10, with 0 being none and 10 being the worse imaginable. The P/S/B that you experience, 4 or more times per month, what would you score it out of _____ /10

11. If ≥ 3/10, is **your P/S/B** greatest while lying in bed and ease within the hour of getting up?

12. Y Okay, is the pain mostly in the neck or the low back?
You are eligible for the Neck/Low back pain group. Is that okay with you?
Y Allocate N Why is that? __________________________________

Follow-up
Confirm email address is correct.
Advise reason is that will be sending them a questionnaire link to complete first night.

Appendix 13. Participant Information Sheet

Curtin University

School of Physiotherapy and Exercise Science

GPO Box U1987
Perth Western Australia 6845

Telephone +61 8 9266 3666
Facsimile +61 8 9266 3699
Email k.briffa@curtin.edu.au
Web curtin.edu.au

Participant Information Sheet

The Effect Of Changing Sleep Posture In The Home Environment On Spinal Symptoms
PhD Candidate: Doug Cary
Supervisors: Associate Professor Kathy Briffa, Professor Michele Sterling

Introduction

Your participation in this research study is voluntary. This study is comparing actual and perceived sleep posture and the possible relationship between sleep posture and morning symptoms.
The researcher will install equipment (2 infrared cameras on stands) in your bedroom, at a convenient time for you. The cameras automatically start at 8.00pm and stop recording at 8.00am. Recording will occur for two nights. The equipment will be collected after the final night. Filming will be repeated after four weeks. An on-line questionnaire will need to be completed on the first day of recording.

Privacy

The images collected on the video will be infrared so likeness to the participants will not be clear, however it may be possible to recognize participants. Only the investigators will view the images and stored images will be password protected accessible only by the investigators and identified by number only. They will be securely archived at Curtin University for twenty-five years.

Contact

Should you have any queries please contact Mr. Doug Cary, 5 William Street, Esperance WA 6450 or by telephoning 90715055 or by emailing douglas.cary@postgrad.curtin.edu.au.

Ethical Details

This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number HR140/2014). The Committee is comprised of members of the public, academics, lawyers, doctors and pastoral carers. If needed, verification of approval can be obtained either by writing to the Curtin University Human Research Ethics Committee, c/-Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au

Appendix 14. Partner Information Sheet

Curtin University

School of Physiotherapy and Exercise Science

GPO Box U1987
Perth Western Australia 6845

Telephone +61 8 9266 3666
Facsimile +61 8 9266 3699
Email k.briffa@curtin.edu.au
Web curtin.edu.au

Partner Information Sheet

The Effect Of Changing Sleep Posture In The Home Environment On Spinal Symptoms
PhD Candidate: Doug Cary
Supervisors: Associate Professor Kathy Briffa, Professor Michele Sterling

Introduction

Your participation in this research study is voluntary. This study is comparing actual and perceived sleep posture and the possible relationship between sleep posture and morning symptoms.
The researcher will install equipment (2 infrared cameras on stands) in your bedroom, at a convenient time for you. The cameras automatically start at 8.00pm and stop at 8.00am. Recording will occur for two nights. The equipment will be collected after the final night. An on-line questionnaire will need to be completed on the first day of recording.

Privacy

The images collected on the video will be infrared so likeness to the participants will not be clear, however it may be possible to recognize participants. Only the investigators will view the images and stored images will be password protected accessible only by the investigators and identified by number only. They will be securely archived at Curtin University for twenty-five years.

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Appendix 15. Participant Consent Form

Curtin University

School of Physiotherapy and Exercise Science
GPO Box U1987
Perth Western Australia 6845
Telephone +61 8 9266 3666
Facsimile +61 8 9266 3699
Email k.briffa@curtin.edu.au
Web curtin.edu.au

Participant Consent Form

The Effect Of Changing Sleep Posture In The Home Environment On Spinal Symptoms

PhD Candidate: Doug Cary

Supervisors: Associate Professor Kathy Briffa, Professor Michele Sterling

- I have read the Participant Information Sheet
- I am 18 years or older, and not pregnant, nor currently receiving medical management for pain, sleep apnea or any other condition that would affect my normal sleep routine
- Any questions I have asked have been answered to my satisfaction. I agree to participate in this research & understand that I can change my mind or stop at any time
- I understand that all information provided is treated as confidential
- I agree to be videoed while sleeping and understand my partner may also be visible
- I agree that research gathered for this study may be published, provided names or any other in formation that may identify me is not used
- I understand the requirements of this study and will be responsible for equipment while in my possession

Participant	Researcher:
Name ______________________________	Name ______________________________
Signature	Signature
Date	Date

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Appendix 16. Partner Consent Form

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Partner Consent Form

The Effect Of Changing Sleep Posture In The Home Environment On Spinal Symptoms
PhD Candidate: Doug Cary
Supervisors: Associate Professor Kathy Briffa, Professor Michele Sterling

- I have read the Partner Information Sheet
- Any questions I have asked have been answered to my satisfaction. I agree to participate in this research & understand that I can change my mind or stop at any time
- I understand that all information provided is treated as confidential
- I agree to be videoed while sleeping
- I agree that research gathered for this study may be published, provided names or any other in formation that may identify me is not used
- I understand the requirements of this study and will be responsible for equipment while in my possession

Partner:	Researcher:
Name ______________________________	Name ______________________________
Signature	Signature
Date	Date

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Appendix 17. Changing Sleep Posture Information Sheet

How you sit and stand during the day influences the load on your spine and soft tissues. In the same way, the positions that you sleep in at night influence your spine. During the day your muscle system resists the forces of gravity but during the night they are largely at rest.

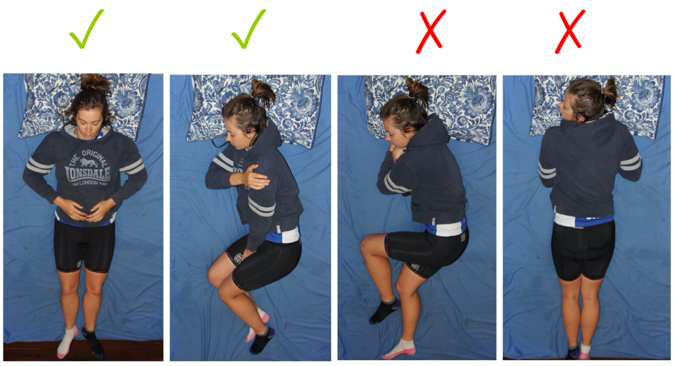
From clinical experience, we have found by explaining and demonstrating the importance of different sleep postures, you can learn to adopt a more comfortable sleep posture. As when changing any habit, your new posture will at first feel different. This is normal and with practice will start to become your natural sleeping habit.

The postures we want you to avoid are lying on your stomach or when on your side with your top leg rolled forward. These postures are believed to increase stress on your spine and consequentially cause pain and stiffness.

The two positions that we would like you to become familiar with are sleeping on your back and sleeping on your side. When on your side, focus on keeping your top knee just behind, your bottom knee, with your top ankle resting in the arch of your foot. This forms your first blocking point. The goal here is to prevent your top knee rolling forward relative to your bottom knee and creating a twisting load on your back and neck.

In addition, create a triangle with your bottom elbow and place your hand against your top shoulder. Triangles are strong and this forms your second blocking point.

Place your top hand between your thighs to act as a diagonal stabilizer, much like on a gate to stop it sagging, it will assist to stop your top knee rolling forward.



Supine Supported Side lying Provocative Side lying Prone

Through the course of the night it is normal to wake several times and people often comment on having a few restless sleeps initially. This is normal and an indication your brain is checking your sleep posture.

Become familiar with these two positions and when you wake up, check and correct your sleeping position appropriately.

Appendix 18. Survey Monkey Online Questionnnaire: Baseline, 4 and 16 Weeks

Sleep Research Questionnaire - Baseline

Section 1

***1. ID Number (provided by researcher)**

***2. Gender**

- Male
- Female

***3. Age**

- 18-20
- 21-25
- 26-30
- 31-35
- 36-40
- 41-45

***4. What is your height in centimeters?**

Height (cms)

***5. What is your weight in kilograms?**

Weight (kgs)

Please answer the next question using these pictures as a reference

SUPINE SSL 3/4 PRONE PRONE

***6. In the last 2 weeks, what percentage (%) of the night do you spend in each position? Total to equal 100.**

Supine

SSL Right or Left

3/4 Prone Right or Left

Prone

Section 1

Page 1

Sleep Research Questionnaire - Baseline

***7. Your highest level of education is?**

- ◯ High school
- ◯ Trade qualification
- ◯ Undergraduate degree
- ◯ Post graduate or higher
- ◯ Other (please specify)

***8. How many mornings a month, would you wake up feeling noticeably stiff or sore?**

- ◯ 0
- ◯ 1-4
- ◯ 5-8
- ◯ 9-12
- ◯ more than 13

***9. If you wake up stiff or sore is it your (you can select more than one)**

- ☐ None stiff or sore
- ☐ Neck
- ☐ Mid Back
- ☐ Lower Back
- ☐ Other (please specify)

***10. Please record your average spine BOTHERSOMENESS, experienced in the morning, for the past 2 weeks.**

No bothersomeness = 0	1	2	3	4	5	6	7	8	9	Worst bothersomeness = 10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

***11. Please record your average spine PAIN, experienced in the morning, for the past 2 weeks.**

No pain = 0	1	2	3	4	5	6	7	8	9	Worst pain = 10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Page 2

Sleep Research Questionnaire - Baseline

***12. Please record your average spine STIFFNESS, experienced in the morning, for the past 2 weeks.**

No stiffness = 0	1	2	3	4	5	6	7	8	9	Worst stiffness = 10
○	○	○	○	○	○	○	○	○	○	○

***13. Please record your average QUALITY OF SLEEP, experienced during the night, for the past 2 weeks.**

Light/Restless = 0	1	2	3	4	5	6	7	8	9	Heavy/Sound = 10
○	○	○	○	○	○	○	○	○	○	○

Section 1

Please record your medications and the reason you take it.

14. Medication 1.
Name/Amount/Frequency/Reason

15. Medication 2.
Name/Amount/Frequency/Reason

16. Medication 3.
Name/Amount/Frequency/Reason

17. Medication 4.
Name/Amount/Frequency/Reason

18. Medication 5.
Name/Amount/Frequency/Reason

19. Medication 6.
Name/Amount/Frequency/Reason

Page 3

Sleep Research Questionnaire - Baseline

20. Interviewers Notes

Section 2

21. When YOUR BACK hurts, you may find it difficult to do some of the things you normally do. This list contains some sentences that people have used to describe themselves when they have BACK PAIN. When you read them, you may find that some stand out because they describe you today. As you read the list, think of yourself today. When you read a sentence that describes you today, fill the box to the left of the sentence. If the sentence does not describe you, then leave the box blank and go on to the next one.
Remember, only mark the sentence if you are sure that it describes you today

- ☐ 1. I stay at home most of the time because of my back.
- ☐ 2. I change positions frequently to try and get my back comfortable.
- ☐ 3. I walk more slowly than usual because of my back.
- ☐ 4. Because of my back, I am not doing any of the jobs that I usually do around the house.
- ☐ 5. Because of my back, I use a handrail to get upstairs.
- ☐ 6. Because of my back, I lie down to rest more often.
- ☐ 7. Because of my back, I have to hold on to something to get out of an easy chair.
- ☐ 8. Because of my back, I try to get other people to do things for me.
- ☐ 9. I get dressed more slowly than usual because of my back.
- ☐ 10. I only stand up for short periods of time because of my back.
- ☐ 11. Because of my back, I try not to bend or kneel down.
- ☐ 12. I find it difficult to get out of a chair because of my back.
- ☐ 13. My back is painful almost all the time.
- ☐ 14. I find it difficult to turn over in bed because of my back.
- ☐ 15. My appetite is not very good because of my back pain.
- ☐ 16. I have trouble putting on my socks (or stockings) because of the pain in my back.
- ☐ 17. I only walk short distances because of my back pain.
- ☐ 18. I sleep less well because of my back.
- ☐ 19. Because of my back pain, I get dressed with help from someone else.
- ☐ 20. I sit down for most of the day because of my back.
- ☐ 21. I avoid heavy jobs around the house because of my back.

Page 4

Sleep Research Questionnaire - Baseline

- [ ] 22. Because of my back pain, I am more irritable and bad tempered with people than usual.
- [ ] 23. Because of my back, I go upstairs more slowly than usual
- [ ] 24. I stay in bed most of the time because of my back.

Section 3

***22. Your SPINE may make it difficult to do some things you normally do. This list contains sentences people use to describe themselves with such problems. Think of yourself over the last few days.**

Due to my spine:

	Yes	Partly/Sometimes	No
I stay at home most of the time	○	○	○
I change position frequently for comfort	○	○	○
I avoid heavy jobs (e.g. cleaning, lifting more that 5kg, gardening etc.)	○	○	○
I rest more often	○	○	○
I get others to do things for me	○	○	○
I have the pain/problem almost all the time	○	○	○
I have difficulty lifting and carrying (e.g. bags, shopping up to 5kg)	○	○	○
My appetite is now different	○	○	○
My walking or normal recreation or sporting activity is affected	○	○	○
I have difficulty with normal home or family duties and chores	○	○	○
I sleep less well	○	○	○
I need assistance with personal care (e.g. washing and hygiene)	○	○	○
My regular daily activities (work, social contacts) are affected	○	○	○
I am more irritable and / or bad tempered	○	○	○
I feel weaker and / or stiffer	○	○	○
My transport independence is affected (driving, public transport)	○	○	○

Sleep Research Questionnaire - Baseline

I require assistance or am slower with dressing	◯	◯	◯
I have difficulty moving in bed	◯	◯	◯
I have difficulty concentrating and / or reading	◯	◯	◯
My sitting is affected	◯	◯	◯
I have difficulty getting in and out of chairs	◯	◯	◯
I only stand for short periods of time	◯	◯	◯
I have difficult squatting and / or kneeling down	◯	◯	◯
I have trouble reaching down (e.g. pickup things, put on socks)	◯	◯	◯
I go up stairs slower or use a rail	◯	◯	◯

Section 4

This questionnaire has been designed to provide information as to how YOUR NECK PAIN has affected your ability to manage everyday life. Please answer every section and mark in each section only the ONE box that applies to you. We realize that you may consider that two of the statements in any one section relate to you, but please just mark the box that most closely describes your problem.

*23. Pain Intensity

- ◯ I have no pain at the moment.
- ◯ The pain is very mild at the moment.
- ◯ The pain is moderate at the moment.
- ◯ The pain is fairly severe at the moment.
- ◯ The pain is very severe at the moment.
- ◯ The pain is the worst imaginable at the moment.

24. Personal Care (washing, dressing etc)

- ◯ I can look after myself normally, without causing extra pain.
- ◯ I can look after myself normally, but it causes extra pain.
- ◯ It is painful to look after myself and I am slow and careful.
- ◯ I need some help, but manage most of my personal care.
- ◯ I need help every day in most aspects of self care.
- ◯ I do not get dressed; I wash with difficulty and stay in bed.

Sleep Research Questionnaire - Baseline

*25. Lifting

- I can lift heavy weights without extra pain.
- I can lift heavy weights, but it gives extra pain.
- Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned, for example, on a table.
- Pain prevents me from lifting heavy weights off the floor, but I can manage light to medium weights if they are conveniently positioned.
- I can lift very light weights.
- I cannot lift or carry anything at all.

*26. Reading

- I can read as much as I want to, with no pain in my neck.
- I can read as much as I want to, with slight pain in my neck.
- I can read as much as I want to, with moderate pain in my neck.
- I can't read as much as I want, because of moderate pain in my neck.
- I can hardly read at all, because of severe pain in my neck.
- I cannot read at all.

*27. Headaches

- I have no headaches at all.
- I have slight headaches that come infrequently.
- I have moderate headaches that come infrequently.
- I have moderate headaches that come frequently.
- I have severe headaches that come frequently.
- I have headaches almost all the time.

*28. Concentration

- I can concentrate fully when I want to, with no difficulty.
- I can concentrate fully when I want to, with slight difficulty.
- I have a fair degree of difficulty in concentrating when I want to.
- I have a lot of difficulty in concentrating when I want to.
- I have a great deal of difficulty in concentrating when I want to.
- I cannot concentrate at all.

Sleep Research Questionnaire - Baseline

*29. Work

- ◯ I can do as much work as I want to.
- ◯ I can do my usual work, but no more.
- ◯ I can do most of my usual work, but no more.
- ◯ I cannot do my usual work.
- ◯ I can hardly do any work at all.
- ◯ I can't do any work at all.

*30. Driving

- ◯ I can drive my car without any neck pain.
- ◯ I can drive my car as long as I want, with slight pain in my neck.
- ◯ I can drive my car as long as I want, with moderate pain in my neck.
- ◯ I can't drive my car as long as I want, because of moderate pain in my neck.
- ◯ I can hardly drive at all, because of severe pain in my neck.
- ◯ I can't drive my car at all.

*31. Sleeping

- ◯ I have no trouble sleeping.
- ◯ My sleep is slightly disturbed (less than 1 hr sleepless).
- ◯ My sleep is mildly disturbed (1-2 hrs sleepless).
- ◯ My sleep is moderately disturbed (2-3 hrs sleepless).
- ◯ My sleep is greatly disturbed (3-5 hrs sleepless).
- ◯ My sleep is completely disturbed (5-7 hrs sleepless).

*32.

- ◯ I am able to engage in all my recreation activities, with no neck pain at all.
- ◯ I am able to engage in all my recreation activities, with some pain in my neck.
- ◯ I am able to engage in most, but not all, of my usual recreation activities, because of pain in my neck.
- ◯ I am able to engage in few of my recreation activities, because of pain in my neck.
- ◯ I can hardly do any recreation activities, because of pain in my neck.
- ◯ I can't do any recreation activities at all.

Section 5

We are aware that emotions play an important part in most illnesses. This questionnaire is designed to help your doctor to know how you feel. Read each item and select the reply which comes closest to how you have been feeling in the past week. Don't take too long over your replies: your immediate reaction to each item will probably be more accurate than a long thought out response.

Sleep Research Questionnaire - Baseline

***33. I feel tense or 'wound up':**

- Most of the time
- A lot of the time
- From time to time, occasionally
- Not at all

***34. I still enjoy the things I used to enjoy:**

- Definitely as much
- Not quite so much
- Only a little
- Hardly at all

***35. I get a sort of frightened feeling as if something awful is about to happen:**

- Very definitely and quite badly
- Yes , but not too badly
- A little, but it doesn't worry me
- Not at all

***36. I can laugh and see the funny side of things:**

- As much as I always could
- Not quite so much now
- Definitely not so much now
- Not at all

***37. Worrying thoughts go through my mind:**

- A great deal of the time
- A lot of the time
- From time to time but not too often
- Only occasionally

***38. I feel cheerful:**

- Not at all
- Not often
- Sometimes
- Most of the time

Section 5

Page 9

Sleep Research Questionnaire - Baseline

***39. I can sit at ease and feel relaxed:**

- ◯ Definitely
- ◯ Usually
- ◯ Not often
- ◯ Not at all

***40. I feel as if I am slowed down:**

- ◯ Nearly all the time
- ◯ Very often
- ◯ Sometimes
- ◯ Not at all

***41. I get a sort of frightened feeling like 'butterflies' in the stomach:**

- ◯ Not at all
- ◯ Occasionally
- ◯ Quite often
- ◯ Very often

***42. I have lost interest in my appearance:**

- ◯ Definitely
- ◯ I don't take so much care as I should
- ◯ I may not take quite as much care
- ◯ I take just as much care as ever

***43. I feel restless as if I have to be on the move:**

- ◯ Very much indeed
- ◯ Quite a lot
- ◯ Not very much
- ◯ Not at all

***44. I look forward with enjoyment to things:**

- ◯ As much as ever I did
- ◯ Rather less than I used to
- ◯ Definitely less than I used to
- ◯ Hardly at all

Sleep Research Questionnaire - Baseline

***45. I get sudden feelings of panic:**

- ◯ Very often indeed
- ◯ Quite often
- ◯ Not very often
- ◯ Not at all

***46. I can enjoy a good book or radio or TV program:**

- ◯ Often
- ◯ Sometimes
- ◯ Not often
- ◯ Very seldom

Section 6

***47. For each question, please select the DESCRIPTION that best describes your answer.**
Please rate the CURRENT (i.e. LAST 2 WEEKS) SEVERITY of your insomnia (difficulty sleeping) problem(s).

	None	Mild	Moderate	Severe	Very Severe
Difficulty falling asleep	◯	◯	◯	◯	◯
Difficulty staying asleep	◯	◯	◯	◯	◯
Problem waking up too early	◯	◯	◯	◯	◯

48. How SATISFIED/DISSATISFIED are you with your CURRENT sleep pattern?

Very Satisfied	Moderately Satisfied	Satisfied	Dissatisfied	Very Dissatisfied
◯	◯	◯	◯	◯

49. How NOTICEABLE to others do you think your sleep problem is in terms of impairing the quality of your life?

Not at all Noticeable	A Little	Somewhat	Much	Very Much Noticeable
◯	◯	◯	◯	◯

50. How WORRIED/DISTRESSED are you about your current sleep problem?

Not at all Worried	A Little	Somewhat	Much	Very Much Worried
◯	◯	◯	◯	◯

51. To what extent do you consider your sleep problem, to INTERFERE with your daily functioning (e.g. daytime fatigue, mood, ability to function at work/daily chores, concentration, memory, etc.) CURRENTLY?

Not at all Interfering	A Little	Somewhat	Much	Very Much Interfering
◯	◯	◯	◯	◯

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Sleep Research Questionnaire - Baseline

Section 7

The following questions relate to your usual sleep habits during the past two weeks only. Your answers should indicate the most accurate reply for the majority of days and nights in the past two weeks.

***52. During the past two weeks, when have you usually gone to bed at night? e.g. 21 for 9.00pm**

Gone to bed time

***53. During the past two weeks, how long (in minutes) does it usually take you to fall asleep each night?**

Time to fall asleep

***54. During the past two weeks, when have you usually gotten up in the morning? e.g. 6 for 6.00am**

Out of bed time

***55. During the past two weeks, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed.)**

Total sleep hours

For each of the remaining questions, check the one best response. Please answer all questions.

***56. During the past two weeks, how often have you had trouble sleeping because you ...**

	Not during the past 2 weeks	Less than once a week	Once or twice a week	Three or more times a week
Cannot get to sleep within 30 minutes	○	○	○	○
Wake up in the middle of the night or early morning	○	○	○	○
Have to get up to use the bathroom	○	○	○	○
Cannot breathe comfortably	○	○	○	○
Cough or snore loudly	○	○	○	○
Feel too cold	○	○	○	○
Feel too hot	○	○	○	○
Had bad dreams	○	○	○	○
Have pain	○	○	○	○

Section 7

***57. During the past two weeks, how would you rate your sleep quality overall?**

Very Good	Fairly Good	Fairly Bad	Very Bad
○	○	○	○

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Sleep Research Questionnaire - Baseline

***58. During the past two weeks, how often have you taken medicine (prescribed or "over the counter" to help you sleep?**

Not during the past 2 weeks	Less than once a week	Once or twice a week	Three or more times a week
○	○	○	○

***59. During the past two weeks, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?**

Not during the past 2 weeks	Less than once a week	Once or twice a week	Three or more times a week
○	○	○	○

***60. During the past two weeks, how much of a problem has it been for you to keep up enough enthusiasm to get things done?**

No problem at all	Only a slight problem	Somewhat of a problem	A very big problem
○	○	○	○

Section 8

This questionnaire asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities.

For each of the following questions, please mark the one that best describes your answer

***61. In general, would you say your health is:**

Excellent	Very Good	Good	Fair	Poor
○	○	○	○	○

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

Much better now than one year ago	Somewhat better now than one year ago	About the same as one year ago	Somewhat worse now than one year ago	Much worse now than one year ago
○	○	○	○	○

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Sleep Research Questionnaire - Baseline

***63. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?**

	Yes, limited a lot	Yes, limited a little	No, not limited at all
Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports	○	○	○
Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	○	○	○
Lifting or carrying groceries	○	○	○
Climbing several flights of stairs	○	○	○
Climbing one flight of stairs	○	○	○
Bending, kneeling, or stooping	○	○	○
Walking more than a kilometre	○	○	○
Walking several hundred metres	○	○	○
Walking one hundred metres	○	○	○
Bathing or dressing yourself	○	○	○

Section 8

***64. During the past 2 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health?**

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Cut down on the amount of time you spent on work or other activities	○	○	○	○	○
Accomplished less than you would like	○	○	○	○	○
Were limited in the kind of work or other activities	○	○	○	○	○
Had difficulty performing the work or other activities (for example, it took extra effort)	○	○	○	○	○

Sleep Research Questionnaire - Baseline

***65. During the past 2 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?**

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Cut down on the amount of time you spent on work or other activities	○	○	○	○	○
Accomplished less than you would like	○	○	○	○	○
Did work or other activities less carefully than usual	○	○	○	○	○

Section 8

***66. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbours, or groups?**

Not at all	Slightly	Moderately	Quite a bit	Extremely
○	○	○	○	○

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

None	Very Mild	MIld	Moderate	Severe	Very Severe
○	○	○	○	○	○

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

Not at all	A Little bit	Moderately	Quite a bit	Extremely
○	○	○	○	○

Sleep Research Questionnaire - Baseline

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

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
Did you feel full of life?	○	○	○	○	○
Have you been very nervous?	○	○	○	○	○
Have you felt so down in the dumps that nothing could cheer you up?	○	○	○	○	○
Have you felt calm and peaceful?	○	○	○	○	○
Did you have a lot of energy?	○	○	○	○	○
Have you felt downhearted and depressed?	○	○	○	○	○
Did you feel worn out?	○	○	○	○	○
Have you been happy?	○	○	○	○	○
Did you feel tired?	○	○	○	○	○

Section 8

***70. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives, etc.)?**

All of the time	Most of the time	Some of the time	A little of the time	None of the time
○	○	○	○	○

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

	Definately true	Mostly true	Don't know	Mostly false	Definately false
I seem to get sick a little easier than other people	○	○	○	○	○
I am as healthy as anybody I know	○	○	○	○	○
I expect my health to get worse	○	○	○	○	○
My health is excellent	○	○	○	○	○

Thank you for completing these questions

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Appendix 19. Ethics Completion Report

Curtin University

Office of Research and Development

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01-Aug-2018

Name: Kathy Briffa
Department/School: School of Physiotherapy and Exercise Science
Email: Kathy.Briffa@curtin.edu.au

Dear Kathy Briffa

RE: Completion report acknowledgment
Approval number: HR140/2014

Thank you for submitting a completion report to the Human Research Ethics Office for the project **The effect of changing sleep posture in the habitual environment on spinal symptoms**.

The completion report was processed by the Human Research Ethics Office on 01-Aug-2018.

The Human Research Ethics Office acknowledges completion of this project and its record will be closed accordingly.

Please ensure that all data are stored in accordance with WAUSDA and Curtin University Policy.

Should you have any queries regarding consideration of your project, please contact the Ethics Support Officer for your faculty or the Ethics Office at hrec@curtin.edu.au or on 9266 2784.

Yours sincerely

[redacted]

Catherine Gangell
Manager, Research Integrity

Appendix 20. Scoping Review: Excluded Studies

Reasons for Exclusion of Studies from Scoping Review

		Reasons for Exclusion					
	Author	Non-English	Same data	Unavailable	Wrong design	Wrong intervention	Wrong outcomes
1	(Aggarwal, Anand, Kishore, & Ingle, 2013)						X
2	(Anonymous, 2011)				X		
3	(Aydin & Cüre, 2006)	X					
4	(Beaumont & Paice, 1992)				X		
5	(Bernstein, 1975)				X		
6	(Boissonnault & Di Fabio, 1996)						X
7	(Borenstein, 2000)				X		
8	(Chen et al., 2013b)						X
9	(Chohan et al., 2013)						X
10	(Courtial, 1970)				X		
11	(Desouzart, Filgueiras, et al., 2014)						X
12	(Desouzart et al., 2015)						X
13	(Desouzart, Vilar, et al., 2014)						X
14	(Deyo, 1993)				X		
15	(Dodick, 2006)				X		
16	(Dzhingarov, 2017)				X		
17	(Endel, 1987)	X					
18	(Ernst, 1995)				X		
19	(Escolar-Reina et al., 2009)						X
20	(Low, Chua, Lim, & Yeow, 2017)						X
21	(Fischer, 1998)	X					
22	(Fossgreen, 1977)	X					
23	(Garvin, Ing, Wu, & Hsu, 2014)				X		
24	(Gordon & Buettner, 2009)						X
25	(Gordon et al., 2007b)		X				
26	(Gordon & Grimmer-Sommers, 2011)						X
27	(Gordon et al., 2002)						X
28	(Jacobson et al., 2010)						X
29	(Jenner & Barry, 1995)				X		
30	(Jenner & Barry, 1995)		X				
31	(Kubota et al., 2003)						X
32	(Lang, 1999)				X		
33	(Lavin, Pappagallo, & Kuhlemeier, 1997)						X
34	(Lee et al., 2016)					X	
35	(Lee & Ko, 2017)						X
36	(Marin et al., 2006)						X
37	(Matsuura, Yamao, Sugita, Aritomi, & Shirakawa, 2008)						X
38	(Murayama et al., 2011)						X
39	(O'Donoghue et al., 2009)						X
40	(Park et al., 1999)						X
41	(Ray & Tooms, 1992)						X
42	(Ray & Tooms, 1992)		X				
43	(Shields, Capper, Polak, & Taylor, 2006)				X		
44	(Tetley, 2000)				X		
45	(Anonymous, 2007)			X			
46	(Verhaert, 2011)						X
47	(Verhaert et al., 2013)						X
48	(Verhaert, Haex, De Wilde, Berckmans, Verbraecken, et al., 2011)						X
49	(Weller, 1979)	X					
50	(Yim, 2015)				X		

Appendix 21. Scoping Review: Data Charting Form

Title. Relationships between sleep posture and non-specific spinal symptoms in adults: A scoping review.

Study Characteristics

- Reference ID
- First author surname and year of publication.
- Country
- Country of origin in which study was completed.
- Study Design

Selection from one of the following study designs;

Experimental

- RCT: studies with features of randomisation, equal control and intervention groups.
- Non-randomised trial: An experimental study in which people are allocated to different interventions using methods that are not random.
- Crossover design: all participants receive the intervention, participants act as own control, often after a wash out period between being control and intervention.
- Pre-post-interventional: baseline measurements taken before intervention period and again after intervention. May also have follow up periods like 1 and 3 months.

Exploratory

- Cohort study - a defined group of people (the cohort with waking spinal symptoms) is followed over time, to examine associations between different interventions (methods of changing sleep posture) received and subsequent outcomes. A 'prospective' cohort study recruits participants before any intervention and follows them into the future.
- Epidemiology - a study from a whole population, collecting range of related data.
- Case controlled - a study that compares participants with waking spinal symptoms with people from the same source population but without waking spinal symptoms ('controls'), to examine the association between

the outcome and prior exposure (e.g. cross sectional: one time point - comparison of sleep postures or longitudinal: two or more time points - being educated about changing sleep posture).

- Cross sectional – across a similar time frame, comparing a range of outcomes.
- Case report - a participant with waking spinal symptoms is described, may involve intervention.
- Case series - same as case report, but more than one person with waking spinal symptoms is reported.
- Single subject case study - single subject evaluated with repeated & regular measures over time (at least 4 per phase), with both baseline and intervention phases.

Participants

Population

- From what group of people was the sample drawn.

Number of subjects

- Total number of subjects actually included in the research.

Gender

- Record the number of male and female or record as Not Stated.

Age

- Record the age range and a measure of central tendency (mean or median) and dispersion (standard deviation or interquartile range) if defined by authors. If not defined, record the range and record as Not Stated.

Study Methods: Posture

Sleep Environment

- Pick from the following; Domestic, Laboratory or Not Stated.

Sleep Postures Defined

- The study defined all the postures measured. Can be a verbal description or a picture of each sleep posture. Answered as Yes or No.

Were the three standard sleep postures used?

- Where the standard sleep postures used, supine, prone and side lying. Answer Yes or No.

Other Sleep Postures Used

- If postures other than the three standard sleep posture were used, what were the other sleep postures? Describe posture or NA (not applicable)

Number of Other Sleep Postures

- In total, how many sleep postures were used including the standard sleep postures. Please note that right and left of the same posture = 1 posture. Answer 1/2/3/4/5/6 or more.

Were outcome measures used for sleep posture

- Yes, No.

Measurement Tool(s) for Sleep Posture

Please select from the following as methods of assessing sleep posture;

- Self-Report, Visual (camera, video, drawing), Bed sensor, Other or Not Stated.

Number of Cameras

- Number of cameras used to collect visual data for analysis. Answer 0/1/2 or 3.

Self-reported Limitations

- Report limitations as discussed by the authors or Not Stated.

Recommendations

- Recommendations as discussed by the authors (e.g., areas of future research, sleeping postures to avoid, recruitment suggestions or Not Stated).

Conclusions (a)

- Can a conclusion regarding a relationship between sleeping posture and waking symptoms be made from the data presented? Please write Y or

N.

Conclusions (b)

- If the answer to Conclusions (a) is Y, what is the conclusion? Please provide a qualitative statement. If the answer to Conclusions (a) was N then write NA.

Study Methods: Symptoms

Anatomical Area(s) Measured

- What areas of the spine were assessed (can be one area, more than one area or all the spine). Answer Cervical, Thoracic, Lumber, All Spine, Not Stated. Also, Other which is for non-spinal areas.

Were outcome measure(s) used for spinal symptoms?

- Y or N.

Type of Symptom Measured

- Which symptoms were described (can be more than one)? Pain, Stiffness, Bothersomeness or Other.

Measurement Tool for Symptoms

- Please detail the name of the measurement tool used to measure symptoms (e.g., VAS, NPRS, specific questionnaire or Not Stated).

Intervention Phase

Was there an intervention?

- Y or N.

If answer No here, then the rest of the questions in this section are answered NA

What was the Intervention

- Describe the intervention.

Intervention duration

- Duration in weeks; 2/4/6 or Other.

Number of Follow-ups

The number of contacts between researchers and participants during the intervention phase, with the aim of reinforcing the intervention. Does not involve reassessment contact.

- Answer 0/1/2/3/4 or Other.

Types of Follow-ups

- List the types of follow up contact used between researcher and participant. Choosing from Phone, Email, Text (SMS), Personal visit, Other or NA.

Outcomes Reported after the Intervention Phase

- Describe the effect of the intervention as Improved (statistically significant), Same (non-significant change) or Not Stated.

Post-Intervention Phase

Follow-up Phase

- Was there a follow up period after the intervention phase? Answer Y or N.

If No, the remainder of questions in this section are answered NA.

Follow-up Duration

- 4/8/12 or Other measured in weeks.

Number of Follow-ups

- The number of contacts between researchers and participants during the follow-up phase, with the aim of reinforcing the intervention. Answer 0/1/2/3/4 or Other.

Outcomes

- Describe what the outcome was (e.g., a change in spinal posture was related to a significant change/no change in symptom or change in sleep quality).

Appendix 22. Manuscript: Identifying relationships between sleep posture and nonspecific spinal symptoms in adults: A scoping review

Open access Research

BMJ Open

Identifying relationships between sleep posture and non-specific spinal symptoms in adults: A scoping review

Doug Cary,[1,2] Kathy Briffa,[1] Leanda McKenna[1]

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ABSTRACT

Objectives The objectives of this scoping review were to identify (1) study designs and participant populations, (2) types of specific methodology and (3) common results, conclusions and recommendations from the body of evidence regarding our research question; is there a relationship between sleep posture and spinal symptoms.

Design Scoping review.

Data sources PEDro, Embase, Cumulative Index to Nursing and Allied Health Literature, Cochrane Library, Medline, ProQuest, PsycINFO, SportDISCUS and grey literature from inception to 10 April 2018.

Data selection Using a modified Arksey and O'Malley framework, all English language studies in humans that met eligibility criteria using key search terms associated with sleep posture and spinal symptoms were included.

Data extraction Data were independently extracted by two reviewers and mapped to describe the current state of the literature. Articles meeting the search criteria were critically appraised using the Downs and Black checklist.

Results From 4186 articles, four articles were identified, of which three were epidemiological and one interventional. All studies examined three or more sleep postures, all measured sleep posture using self-report and one study also used infrared cameras. Two studies examined symptoms arising from the lumbar spine, one the cervical spine and one the whole spine. Waking pain and stiffness were the most common symptoms explored and side lying was generally protective against spinal symptoms.

Conclusions This scoping review highlights the importance of evaluating sleep posture with respect to waking symptoms and has provided preliminary information regarding relationships between sleep posture and spinal symptoms. However, there were not enough high-quality studies to adequately answer our research question. It is recommended future research consider group sizes and population characteristics to achieve research goals, that a validated measure be used to assess sleep posture, that characteristics and location of spinal symptoms are clearly defined and that the side lying posture is subclassified.

Strengths and limitations of this study

- This is the first scoping review collating and synthesising the available literature on sleeping posture and non-specific spinal symptoms.
- A critical appraisal of evidence assessment was undertaken for each included study.
- The lack of studies and small group sizes prevented firm recommendations regarding all sleep postures.

INTRODUCTION

Cervical and lumbar symptoms like pain are the leading cause of musculoskeletal disability in most countries and most age groups.[1] Of those who report cervical and lumbar pain, the proportion is higher in females for both cervical (59%)[2] and lumbar (52%) pain.[3] The prevalence of both cervical and lumbar pain has increased markedly over the past 25 years (cervical 21.1% and lumbar 17.3%), and these rates are expected to continue rising.[1] Cervical and lumbar pain contribute to large economic and societal costs and are major sources of work disability, being either the first or second ranked cause of years lived with disability between the ages of 20 and 79 years.[1 4 5] Research indicates that remissions in symptoms are temporary rather than permanent[6 7] and cervical and lumbar pain becomes chronic in 25%–60% of cases.[8] Other types of symptoms like stiffness and bothersomeness, still important to patients, are less well investigated.[9 10] Identification of modifiable risk factors contributing to the onset and chronicity of cervical and lumbar pain and other symptoms is critical[11] to improve the management of cervical and lumbar pain.

A potentially modifiable risk factor that aggravates spinal symptoms is sleep posture. Sleep is considered essential for human mental and physical recovery. Yet, every night some people go to bed, only to wake with spinal symptoms not present the prior evening, while others with existing spinal symptoms, wake with exacerbations of their symptoms.[12 13] For example, in young air force personnel, 33% experienced their most intense spinal pain during the evening and on first waking.[12] It has been postulated that poor sleep posture may be a factor in the development of both waking cervical[14–16] and lumbar symptoms.[17 18]

Habitual sleep postures may influence the amount of load applied to spinal tissues when sleeping. Compressive load due to gravity and muscle contraction[19 20] is likely to be far more during the day than during the night. In a 25-year review on the fundamentals of spinal biomechanics, it was noted that spinal movements decreased under a superimposed compression load. The author postulated this was due to increased anular stiffness and increased zygapophyseal joint (ZPJ) contact.[21] Conversely, when lying down, the sources of spinal compression are minimal, creating a low compression environment, potentially allowing an increased range of spinal movement. The combination of increased range and asymmetrical loading posture may result in altered and/or additional loading of viscoelastic collagenous restraints like the ZPJ capsule and ligaments.[22] Viscoelastic tissues are vulnerable to sustained or repeated low elongation loads, and undergo predictable mechanical and viscoelastic changes. Ligaments in feline spines exposed to 60 min of repeated low load, demonstrate a significant increase in the expression of pro-inflammatory chemicals, compared with control ligaments from the same spine, indicating acute inflammation and tissue degradation in ligaments subjected to the cyclic loading.[23] Additionally, sustained non-symmetrical sleep postures can induce structural spinal changes in humans.[24 25] Sleep postures have been shown to be modifiable[17 26] and identification of modifiable risk factors related to spinal pain, have been highlighted as a priority in managing disabling lumbar pain.[27]

Some sleep postures, such as prone, are clinically believed to increase load on spinal tissues, reducing recovery and provoking waking spinal symptoms.[18 28 29] While some sleep research has examined, the role sleep posture may have on spinal symptoms,[15 17 30] there has been no synthesis of the literature in regard to sleep posture and spinal symptoms.

METHODS

Search framework

This scoping review was developed using the methodological framework proposed by previous authors,[31] further refined by other independent authors and institutes[32–34] and reported in line with key Preferred Reporting Items for Systematic Reviews and Meta-Analyses for scoping reviews (PRISMA) guidelines.[35]

Research question

Following an individual review of the literature and a group meeting, authors' consensus was reached to determine the following research question; is there a relationship between sleep posture and spinal symptoms?

Aim and objectives

The aim of this scoping review was to gain a clear understanding of the current knowledge base in relation to the identified research question. To achieve this aim, an iterative process involving electronic meetings and communication between authors was used to determine the following research objectives:

- Identify what study designs and participant populations have been studied to answer the research question.
- Identify the types of specific methodology used in the body of evidence to address the research question.
- Identify common results, conclusions and recommendations from the body of evidence regarding the research question.

Eligibility criteria

Eligibility criteria were based on the population, intervention, comparison and outcome (PICO) framework. A draft list of eligibility criteria was initially determined following the independent screening of relevant articles by two reviewers. Criteria were then developed iteratively between two reviewers and a finalised list of criteria were uploaded to Covidence,[36] as a reference for data charting reviewers.

Inclusion criteria

For inclusion in this scoping review, the prior research needed to study participants 18 years or older, with either pain, stiffness or bothersomeness in the cervical, thoracic or lumbar spine. Any observational or interventional study examining the relationship between sleep posture and spinal symptoms was considered. Articles that either compared sleep posture change (eg, before and after an intervention) or had no comparator (eg, epidemiological) were included. Articles needed to use a subjective or objective measure for symptoms and sleeping posture.

Exclusion criteria

Articles were excluded if they involved animals, cadavers or included participants diagnosed with sleep apnoea, spinal stenosis, migraine, red flag pathologies (eg, neoplasm, inflammatory conditions, fractures or infections); participants with pain of known non-spinal origin (eg, kidney disease, postoperative pain, temporomandibular joint, shoulder pain); participants with neurological conditions (eg, multiple sclerosis, cerebrovascular accident); or participants who were unable to move freely in bed (eg, using continuous positive airway pressure therapy or in the last trimester of pregnancy). Articles were excluded if they did not isolate the intervention when a group of interventions were implemented (eg, spinal injection and sleeping posture) or if they compared sleep systems (eg, mattress, base and or pillow) or changes in sleep systems but did not report the change in sleep posture. Further, articles using actigraphy to measure movement or articles that only examined the quality or efficacy of sleep were excluded. Finally, editorials, opinion-based articles, review articles (systematic or narrative) and articles not written in English were excluded.

Cary D, et al. BMJ Open 2019;0:e027633. doi:10.1136/bmjopen-2018-027633

Patient and public involvement

Patients and the public were not involved in this scoping review.

Search terms and strategy

The PICO framework was used to assist in the collation of all elements relevant to clinical research questions. Population: Terms used for the search strategy were chosen to be representative of the areas and symptoms, likely to be experienced by a population with non-specific spinal symptoms. Non-specific symptoms are those not related to fracture, infection, inflammatory disease, tumour or spinal stenosis. Intervention: Terms representative of interventions aimed at changing sleep posture in association with spinal symptoms were considered for inclusion, while other terms not associated with spinal symptoms, for example, apnoea were excluded. Comparison: Terms were considered that were indicative of any type of comparison. Outcome: Any terms to indicate the subjective measure of pain, stiffness or bothersomeness or objective measure used to evaluate sleep posture were considered.

Identified key search terms were then used in the search strategy to identify all relevant articles. An initial search was conducted in two of the four databases, recommended[37] for physiotherapy related topics; PEDro and Embase (via Ovid) from inception to December 2017. The initial search was used to determine if the search terms and strategy were appropriate, and informed the development of the final search terms and strategy.

The final search strategy was conducted using the search terms and Boolean logic as described in online supplementary file 1 and adapted for eight electronic databases (PEDro, Embase, Cumulative Index to Nursing and Allied Health Literature, Cochrane Library, Medline, ProQuest, PsycINFO, SportDISCUS) with the assistance of a health sciences information specialist. Grey literature (espace, Google Scholar (top 100 references scanned for relevance) and Web of Science) was searched for difficult to locate or unpublished material that had not already been included. The final step involved manual searching the reference sections of relevant articles and publications by key authors for additional articles, not identified in the original search.

Study selection

All search results were imported into the reference management software package, EndNote V.X8[38] and duplicates removed. Remaining results were imported into Covidence[36] and additional duplicates removed. Using Covidence, two reviewers independently performed level 1 (title and abstract) and level 2 (full text) screening, based on the eligibility criteria. Differences of opinion in which articles progressed to the next level were first resolved with discussion between reviewers and if necessary, with input from a third reviewer.

Data charting

The data charting form was developed and revised iteratively between reviewers to ensure data relevant to the three research objectives were collected. A definitions and instructions document was developed to ensure that data were collected consistently by the independent reviewers. The data charting form was then independently pilot tested in duplicate on a random sample of four potential articles. Following identification of articles for inclusion in this review, data were independently charted in duplicate using a data charting form created in Excel and based on the three research objectives. An attempt was made to contact authors of eligible articles where authors reported that data relevant to our scoping review had been collected but was not publicly available, and to clarify points relevant to our data charting.

Quality of evidence

Non-assessment of methodological quality and the risk of bias are consistent with current guidelines on conducting a scoping review.[32 34] However, a focus of this scoping review was on methodology; therefore, a methodological assessment of quality was included. The Downs and Black checklist[39] was chosen, as it has documented criterion validity, face and content validity, intrarater (r=0.88) and inter-rater reliability (r=0.75) and guidelines for use.[40] A modified version of the Downs and Black checklist,[41] where a dichotomous score for power (question 27), was used. As a result, the maximum score for randomised trials was 28 and for non-randomised trials it was 25. The Downs and Black checklist was independently completed for each article in duplicate. Differences in scoring were first resolved by consensus between reviewers and if required, by a third independent reviewer. Study limitations noted by authors were collected to compliment the Downs and Black checklist.

RESULTS

Search results

An overview of the article identification process is provided in the PRISMA flow diagram in figure 1. Articles excluded due to wrong outcomes were those that did not include a measure of sleep posture or only examined sleep posture and not symptoms, tested a sleeping system (eg, mattress or pillow) in relation to spinal symptoms but not posture, or studied sleep posture in relation to sleep quality. Articles excluded due to wrong study design included treatment guidelines, opinion and editorial pieces and summaries.

Study design and population characteristics

The designs of the four included studies were mixed (table 1).

Methodology: Sleep posture measurement

All studies examined participants in their domestic environment (table 2) and described as a minimum the three common sleep postures; supine, side lying and prone. One study described four sleep postures, dividing side lying into two sleep postures and named them supportive side

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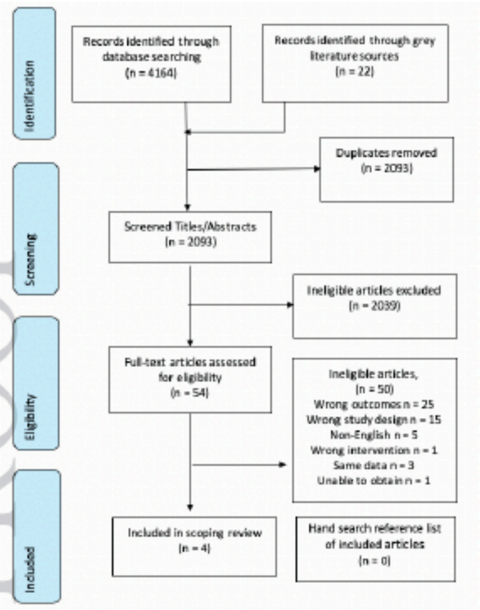

Figure 1 PRISMA flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

lying and ¾ side lying.[42] Another described five postures, adding 'upright' and 'varies', to the common three sleep postures.[13] One study used three different postures, but combined side lying and prone for analysis, due to small number of prone sleepers, of whom none reported lumbar pain.[43] All studies used self-report questionnaires to assess sleep posture. Studies focused on different time points when questioning about sleep posture. Two specifically focused on night and waking posture; 'in what sleep posture do you usually go to sleep', 'in what sleep posture do you usually wake up' and 'in what sleep posture do you spend most of the night'[13] (p7), and 'which posture most closely resembles the posture you are lying in when you fall asleep?' and 'which posture most closely resembles the posture you are lying in when you wake up?'.[42] The other two studies were non-specific, 'usual sleep posture'[43] (p335) and 'informal questionnaire for… sleeping position'[17] (p237). In addition to using self-report, the authors of one study used an objective method of assessment, twin camera infrared video recording, to verify sleep posture.[42]

Methodology: measurement of symptoms

The anatomical location, characteristics and method of measuring spinal symptoms are presented in table 2. One study included non-spinal symptoms (eg, hip and legs) classified as 'other'.[42] All studies examined pain (with two studies examining additional symptoms), but differed in regard to examining intensity, frequency, period of symptoms and diurnal/nocturnal presence. In one study, participants answered a 'question on LBP history, such as present and past low back history'[43] (p333) and another asked participants 'the frequency and location of morning symptoms of spine pain and stiffness that occurred during the past month'[42] (p2). In the other two studies, one described the frequency and duration of morning pain and stiffness over the prior week, but not intensity[13] while the other used a Visual Analogue Scale (VAS) to measure pain intensity 'at moment of response' but not frequency or duration[17] (p237).

Methodology: interventions and follow-ups

Only participants in the treatment group of the intervention study[17] received sleep posture education. Those with dorsal or lumbar symptoms were advised to sleep supine, those with cervical symptoms were advised to sleep in side lying and prone sleepers were advised to adopt either of the prior recommended sleep postures. Participants were also educated about the use of pillows and how to get up and lie down. The control group received no instruction and neither group received further contact until reassessment. The intervention phase lasted 4 weeks. A significant reduction in pain was reported in the treatment group but not the control group. However, sleep

Table 1 Mapping of study design and population characteristics

Author	Study design	Population type	Sample size (Gender)	Age M (SD)
Abanobi *et al*,[43] 2015	Epidemiological: case controlled	Welders in Owerri, Nigeria	100 (male=100)	35 (9)
Cary *et al*,[42] 2016	Epidemiological: cross-sectional	Population of convenience in Esperance, Western Australia	15 (male=7)	44 (17)
Desouzart *et al*,[17] 2016	Controlled pilot	Elderly participants in physical activity programme at Polytechnic Institute of Leiria, Portugal	20 (male=0)	62 (4)
Gordon *et al*,[13] 2007	Epidemiological: cross-sectional	Every third household in Port Lincoln in South Australia	812 (male=261)	Female 61 (10) Male 59 (11)

M = mean, SD = standard deviation

Cary D, *et al*. *BMJ Open* 2019;0:e027633. doi:10.1136/bmjopen-2018-027633

Table 2 Mapping of sleep posture measurement and symptoms

Author	Sleep environment	Standard three sleep postures	Number of sleep postures	Sleep posture outcome measurement	Anatomical area	Symptom type	Symptom(s) characteristics	Symptom outcome measurement
Abanobi *et al*,[43] 2015	Domestic	Y	3	SR	Lumbar	Pain	Past and present history	Questionnaire—face-to-face interview
Cary *et al*,[42] 2016	Domestic	Y	4	SR+video recording	Cervical, lumbar, both, other	Pain, stiffness	Frequency (month) waking symptoms	Questionnaire written
Desouzart *et al*,[17] 2016	Domestic	Y	3	SR	All spine	Pain	Intensity	Questionnaire written—pain VAS
Gordon *et al*,[13] 2007	Domestic	Y	5	SR	Cervical	Pain, stiffness, HA, shoulder blade/arm pain	Frequency (week), duration Waking symptoms	Questionnaire—structured telephone interview

HA = headache; SR = self-report; VAS = Visual Analogue Scale; Y = yes.

posture was not objectively confirmed at baseline or after the intervention period.

Results, conclusions and recommendations

Results from all studies reported trends or significant associations between spinal pain and certain sleep postures (table 3). The authors from three studies reported increased symptoms, one associated with supine[43] one upright[13] and the other in prone or ¾ side lying[42] sleep postures. The authors from two studies reported significantly decreased symptoms, one with side lying[13] and the other a combination of side lying and supine.[17] In the intervention study, the authors reported a significant reduction in pain VAS for the intervention group but not the control group.[17] Between-group comparisons were not reported, possibly because it was a pilot study. We used an online calculator[44] to determine an effect size with 95% CIs between groups, using baseline to postintervention data in two steps. Baseline to postintervention change was used because a significant difference between groups existed at baseline. First, a pooled SD for each group was calculated for change from baseline to final measure. Then this pooled SD from each group was used to calculate the between group effect size and 95% CI (see table 3). The resultant CI indicates that significant differences between groups were unlikely. To calculate an effect size for Cary *et al*,[42] the independent samples Jonckheere-Terpstra test[45] was used to calculate a z-score, which was then converted into an effect size (r_j).[46]

Conclusions from authors of all four studies were that sleep posture could increase or decrease spinal pain, and that addressing sleep posture could reduce the development of spinal pain. Using self-report, side lying was reported as protective of spinal symptoms[13 17] and participants that slept in supported side lying were found to have less symptoms than those sleeping in ¾ side lying or prone.[42] In regard to supine, one study found supine increased the likelihood of lumbar pain by 1.9 times,[43] another study recommended supine in combination with side lying sleep postures to reduce lumbar pain[17] and a third reported supine was not significantly protective of cervical waking symptoms.[13]

Two studies recommended clinicians consider sleep posture to reduce cervical[13] and lumbar symptoms.[17]

Quality of evidence and author reported limitations

The quality of evidence is summarised in table 4. The Downs and Black checklist contains 27 questions distributed over five domains; reporting (ie, aims, sampling and methods); external validity (ie, generalisability); internal validity (ie, study design, selection bias, performance and reporting bias); confounding and power.[39] Using the Downs and Black checklist as the appraisal tool, evidence levels have previously been categorised as strong (>75%), moderate (50%–74%), limited (25%–49%) and poor quality (<24%).[47] Questions 4, 8, 9, 13, 14, 15, 19, 23, 24 and 26 (see table 4 for details) were not applicable to study designs that did not include an

Table 3 Mapping of results, conclusions and recommendations

Author	Results	Conclusions	Recommendations
Abanobi *et al*,[43] 2015	ORs for LBP were in relation to a combined group of prone and side lying sleeping. 'Sleeping with back (face up) increases the risk of developing LBP by 1.9 times.' (p. 355) (95% CI 0.43 to 8.56)*	'The result showed the possibility of reducing the burden of LBP by appropriate training and improvement in habits such as…bad sleeping postures.' (p. 336)	Not provided
Cary *et al*,[42] 2016	'The time spent in each of the sleeping postures… expressed as a percentage of the time spent asleep, did not differ significantly according to the level of morning symptoms' (p. 5). Independent Samples Jonckheere-Terpstra Test; supine r_j=0.03; SSL r_j=0.00; ¾ SL r_j=0.34; prone r_j=0.31.	'Participants who spent greater periods of time in SSL, had less mornings of symptoms per month than those that slept in ¾ SL or prone.' (p. 5)	Not provided
Desouzart *et al*,[17] 2016	No between-group comparison reported. Between group effect size calculated to be 0.81 (95% CI −0.11 to 1.72).	'It may be concluded that the indication of the ideal way to lie down, which corresponds to a recommended sleeping posture with the ideal position to place the pillows, as well as the ideal way to get up.' (p. 239)	Ideal sleep posture, pillow use and way to get up, as per experimental group, 'is an added value for the prevention and decrease of the pain and/or discomfort in the spine in active seniors.' (p. 239)
Gordon *et al*,[15] 2007	'Subjects who reported sleeping mostly in an upright position were significantly more likely to report all waking symptoms of interest compared with subjects who slept in other positions.' (p. 6) Waking cervical pain OR 2.5 (95% CI 1.1 to 5.5), cervical stiffness OR 2.6 (95% CI 1.1 to 5.8), headache OR 2.2 (95% CI 1.0 to 5.0), scapular/arm pain OR 2.5 (95% CI 1.1 to 5.3). 'Supine…was not found in this study to be significantly protective of waking symptoms, when compared with other sleep positions.' (p. 6) Waking cervical pain OR 1.4 (95% CI 0.8 to 2.5) and cervical stiffness OR 0.9 (95% CI 0.5 to 1.6). 'Prone…was not significantly associated with waking symptom' (p. 6). Cervical pain OR 1.5 (95% CI 0.7 to 3.2) and cervical stiffness OR 1.1 (95% CI 0.5 to 2.6). 'Subjects who reported that they slept mostly on their side were significantly less likely to report waking cervical pain… compared with subjects who slept in any other position.' (p. 4) Waking cervical pain OR 0.6 (95% CI 0.4 to 0.9) and scapular/arm pain OR 0.7 (95% CI 0.5 to 0.9).		'On the basis of this research, SL can be confidently recommended as the best sleep position in terms of minimising waking symptoms.' (p. 6) 'Need for health professionals to consider individual's sleep position and waking symptom history, as part of clinical reasoning for treatment, and when developing a management plan for patients with troublesome waking symptoms.' (p. 6)

*The CI was recalculated as it was suspected wrong due a typographical error. The original value was 0.431.
¾ SL= ¾ side lying; rj= effectsize r for Jonckheere-Terpstra test .
LBP = lowback pain; SSL = supportedside lying; VAS = VisualAnalogue Scale.

intervention group and were therefore excluded from the three epidemiological studies.[15 42 43] Question 27 was applicable for all but the cross-sectional study.[42] In the reporting subsection, questions 1–10, studies were well documented with one different applicable question not completed by each study, enabling readers to draw unbiased assessments of each study's findings. Questions 11–13 (external validity) were poorly reported, with all studies failing to quantify the proportion of participants that were asked, relative to the proportion of participants that were accepted into studies. All studies reported using either random[15 17 43] or consecutive sampling.[42] Internal validity, questions 14–20, examined measurement bias and apart from question 15 were well documented. In all studies, no attempt was made to blind researchers measuring the outcome variables. However, in one epidemiological study, the interview method precluded the need for blinding of interviewers.[15] All the remaining questions were well documented, except for question 25 which examined confounding factors. This was poorly documented except for one study,[48] in which a multivariate analysis was reported in a subsequent study, using the same data. The body of evidence in this scoping review is rated as moderate to strong quality.

Authors identified reliance on self-report to examine sleep posture[17] and symptoms[48] as a limitation. Authors identified small sample sizes, as limiting their ability to draw firm conclusions from the obtained results.[15 17] Authors identified restricted time as a limitation, for the period available for data collection,[43] and for participants to learn a new sleeping habit.[17] Limitations as reported by authors are described in online supplementary file 2.

Table 4 Critical appraisal of included studies using the Downs and Black checklist

Section	Questions		Abanobi *et al*,[43] 2015	Cary *et al*,[42] 2016	Desouzart *et al*,[17] 2016	Gordon *et al*,[18] 2007
Reporting	1	Is the hypothesis/aim/objective of the study clearly described?	Y	Y	Y	Y
	2	Are the main outcomes to be measured clearly described in the Introduction or Methods section?	N	Y	Y	Y
	3	Are the characteristics of the patients included in the study clearly described?	Y	N	Y	X
	4	Are the interventions of interest clearly described?	X	X	Y	X
	5	Are the distributions of principal confounders in each group of subjects to be compared clearly described?	*Y	X	*Y	*Y
	6	Are the main findings of the study clearly described?	Y	Y	Y	Y
	7	Does the study provide estimates of the random variability in the data for the main outcomes?	Y	Y	Y	Y
	8	Have all important adverse events that may be a consequence of the intervention been reported?	X	X	N	X
	9	Have the characteristics of patients lost to follow-up been described?	X	X	Y	X
	10	Have actual probability values been reported (eg, 0.035 rather than<0.05) for the main outcomes except where the probability value is less than 0.001?	Y	Y	Y	N
External validity	11	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	Y	Y	N	Y
	12	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?	U	N	N	N
	13	Were the staff, places and facilities where the patients were treated, representative of the treatment the majority of patients receive?	X	X	Y	X
Internal validity: bias	14	Was an attempt made to blind study subjects to the intervention they have received?	X	X	U	X
	15	Was an attempt made to blind those measuring the main outcomes of the intervention?	X	X	N	X
	16	If any of the results of the study were based on 'data dredging', was this made clear?	Y	Y	Y	Y
	17	In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case–control studies, is the time period between the intervention and outcome the same for cases and controls?	Y	X	Y	X
	18	Were the statistical tests used to assess the main outcomes appropriate?	Y	Y	Y	Y
	19	Was compliance with the intervention/s reliable?	X	X	U	X
	20	Were the main outcome measures used accurate (valid and reliable)?	Y	Y	Y	Y

Continued

Table 4 Continued

Section	Questions		Abanobi et al,[43] 2015	Cary et al,[42] 2016	Desouzart et al,[17] 2016	Gordon et al,[13] 2007
Internal validity: confounding	21	Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case–control studies) recruited from the same population?	Y	X	Y	Y
	22	Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case–control studies) recruited over the same period of time?	Y	X	Y	X
	23	Were study subjects randomised to intervention groups?	X	X	Y	X
	24	Was the randomised intervention assignment concealed from both patients and healthcare staff until recruitment was complete and irrevocable?	X	X	U	X
	25	Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	N	N	N	Y
	26	Were losses of patients to follow-up taken into account?	X	X	Y	X
Power	27	Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?	N	X	N	N
Score			14/17	9/12	19/28	12/14
Percentage			82	75	68	86

N = no = 0, Y = yes = 1, *Y = 2 points, U = unable to determine = 0, X = not applicable (see Quality of Evidence section).
Evidence levels = strong (>75%), moderate (50%–74%), limited (25%–49%) and poor quality (<24%).[47]

DISCUSSION

To our knowledge, this scoping review is the first to establish the body of evidence regarding the research question; relationships between sleeping posture and spinal symptoms. Generally, there was limited available research. In regard to objective 1; research designs and populations studied for the research question, a variety of study designs and participant populations were used. One study was a controlled pilot trial. With regard to objective 2; types of specific methodology used to address the research question, sleep was assessed in a domestic environment in all studies, with self-report used to measure sleep posture in all studies. Pain was the most common outcome measure of symptoms. In respect to objective 3; results, conclusions and recommendations, authors recommended side lying as the sleep posture least likely to provoke cervical or lumbar spinal symptoms. Studies included in this scoping review were of moderate to strong quality as assessed using the Downs and Black critical appraisal tool. Nonetheless, considerably more research, including longitudinal studies, is required before causal relationships between sleep posture and spinal symptoms could be concluded.

The study designs identified in this scoping review were appropriate to use for the research question. The variety of study designs prevented data pooling and a scoping review remained the most appropriate approach to synthesise the research. The age and gender ratios of included studies were not representative of typical cervical and lumbar pain populations.[1–5] Generalisation of the results of the included studies needs to be considered with some caution because of a strong gender bias in two studies[17 43] and a restricted age of included participants in one study.[17] In general, small sample sizes were used. The type of study designs and patient populations identified in this scoping review have provided preliminary information regarding relationships between sleep posture and spinal symptoms, but there were not enough high-quality studies to adequately answer our research question.

The most common adult sleep postures are side lying, supine and prone,[28 49 50] which were the postures examined by the studies in this review. Side lying is the sleep posture that greater than 60% of European adults adopt for the majority of the night.[28 49 50] For this reason, one study divided side lying into two sleep postures, based on symmetry and plausible spinal load. These authors identified a trend that participants spending more time in symmetrical side lying reported less morning symptoms than those in asymmetrical side lying.[42] Although all studies in this review used self-report to report sleep posture, some authors identified this as a limitation[13 17 42] and inaccuracy associated with sleep posture self-report can be as high as 33%.[51 52] It, therefore, seems prudent to not rely purely on self-report and clinicians would have higher confidence when advising people with pain about sleep posture, if research included both self-report and a valid and reliable measure of sleep posture, such as included in one study.[42]

The anatomical features of the cervical and lumbar spine are different and it is plausible that sleeping postures could affect each area differently. For example, studies in this review indicated sleeping in supine was

Cary D, et al. BMJ Open 2019;0:e027633. doi:10.1136/bmjopen-2018-027633

associated with lumbar symptoms,[43] but not associated with cervical symptoms.[15] Pain was measured in all studies, which is appropriate given cervical and lumbar pain are leading contributors across all age groups and countries to musculoskeletal disability.[1] However, characteristics like intensity, frequency or the onset time of pain were not consistently measured and are important to better understand the overall impact pain is having on daily function.[53] With regard to the relationship between sleep posture and time of onset of spinal symptoms, only half of the studies examined waking symptoms.[15 42] Waking spinal symptoms are rarely present every morning, which may be due to an individual's variation in sleep posture routine. To better understand the temporal relationships between sleep posture and spinal symptoms, it would be important to record spinal symptoms on first waking.

Spinal pain is a major and growing global health problem with increasing rates of disability.[1] For the past 20 years, there has been a strong biomedical focus on pathoanatomy as the cause of spinal pain. However, in the case of lumbar pain, only 8%–15% of cases has a specific tissue identified as the cause.[54] Concurrently, there has been an escalation in imaging, opioid prescription, injections and surgery, with questionable benefit[55–57] and higher risks.[8 58] Changing physical risk factors like type of movement pattern,[59] level of strength and conditioning[60 61] and sustained or repeated postures,[62 63] are relatively risk free, cost-effective and show great potential. Sleep posture is an example of a sustained physical risk factor that is modifiable.[64 65] Clinical recommendations by authors included in this review included considering sleep posture when developing management plans for people with waking spinal symptoms[15] and education to change symptomatic sleep postures.[43] With regard to recommending a sleep posture to minimise spinal symptoms, this review finds that the side lying posture for the cervical spine,[15] and side lying and supine were the sleep postures recommended by authors for those with lumbar spinal pain.[17] However, there is a lack of high-quality studies from which to draw firm recommendations.

Based on the findings of this scoping review, we offer the following recommendations to improve the quality of future research. Research samples should be large enough to achieve statistical goals and sample demographics should be representative of those in the broader population with cervical and lumbar pain. Ideally studies should account for confounding factors such as age and gender through study design or statistical analysis. It would be preferable to differentiate spinal symptoms according to location, rather than considering spinal symptoms as a single group, due to differences in spinal anatomy, function and referral of symptoms. It is also recommended to divide spinal symptoms into categories such as pain, stiffness and bothersomeness, to determine if one or more have greater clinical relevance. Using a valid, objective measure of sleep posture instead of self-report, would also enable determination of time spent in each sleep posture and the number of sleep posture changes. As side lying appears to be associated with less cervical and possibly spinal symptoms generally, it would be worthwhile in future research to confirm this relationship and to further explore whether some subtypes of side lying postures are less provocative of spinal symptoms than others. It would also be informative to consider the temporal aspect of spinal symptoms. That is, recording spinal symptoms on first waking before they are influenced by daytime activities. Sleep posture is potentially modifiable following education[17] and education is a non-invasive and low-cost intervention which should be further explored in future research using larger scale longitudinal studies.

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Contributors DC, LM and KB designed the study. DC and LM collected data and conducted data analysis. DC wrote the manuscript. DC and LM undertook interpretation of findings and were involved in drafting the manuscript. All authors were involved in revision of the manuscript gave final approval for submission and publication.

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Competing interests None declared.

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REFERENCES

1. Hurwitz EL, Randhawa K, Yu H, *et al*. The global spine care initiative: a summary of the global burden of low back and neck pain studies. *Eur Spine J* 2018;27:1–6.
2. Côté P, Cassidy JD, Carroll LJ, *et al*. The annual incidence and course of neck pain in the general population: a population-based cohort study. *Pain* 2004;112:267–73.
3. Hoy D, Bain C, Williams G, *et al*. A systematic review of the global prevalence of low back pain. *Arthritis & Rheumatism* 2012;64:2028–37.
4. Ekman M, Johnell O, Lidgren L. The economic cost of low back pain in Sweden in 2001. *Acta Orthop* 2005;76:275–84.
5. Wasiak R, Kim J, Pransky G. Work disability and costs caused by recurrence of low back pain: longer and more costly than in first episodes. *Spine* 2006;31:219–25.
6. Croft PR, Lewis M, Papageorgiou AC, *et al*. Risk factors for neck pain: a longitudinal study in the general population. *Pain* 2001;93:317–25.
7. Hestbaek L, Leboeuf-Yde C, Kyvik KO, *et al*. The course of low back pain from adolescence to adulthood: eight-year follow-up of 9600 twins. *Spine* 2006;31:468–72.
8. Manchikanti L, Singh V, Datta S, *et al*. Comprehensive review of epidemiology, scope, and impact of spinal pain. *Pain Physician* 2009;12:35–70.
9. Hodges P, van den Hoorn W, Dawson A, *et al*. Changes in the mechanical properties of the trunk in low back pain may be associated with recurrence. *J Biomech* 2009;42:61–6.
10. Cho Y, Song Y, Cha Y, *et al*. Acupuncture for chronic low back pain. *Spine* 2013;38:549–57.
11. Croft PR, Dunn KM, Raspe H. Course and prognosis of back pain in primary care: the epidemiological perspective. *Pain* 2006;122:1–3.

12. Desouzart G, Vilar E, Melo F, Matos R, *et al*. eds. *Human bed interaction: a methodology and tool to measure postural behavior during sleep of the air force military*. Heraklion, Greece: 3rd International Conference on Design, User Experience, and Usability, 2014.
13. Gordon S, Grimmer K, Trott P. Sleep position, age, gender, sleep quality and waking cervico-thoracic symptoms. *Internet Journal of Allied Health Sciences and Practice* 2007;5.
14. Corrigan B, March L. Cervical spine dysfunction: a pain in the neck. *Patient Management* 1984;8:48–53.
15. Gordon SJ, Trott P, Grimmer KA. Waking cervical pain and stiffness, headache, scapular or arm pain: gender and age effects. *Aust J Physiother* 2002;48:9-15.
16. McKenzie R. *The cervical and thoracic spine: mechanical diagnosis and therapy*. Waikanae: Spinal Publications, 1990.
17. Desouzart G, Matos R, Melo F, *et al*. Effects of sleeping position on back pain in physically active seniors: A controlled pilot study. *Work* 2015;53:235–40.
18. Gracovetsky SA. The resting spine. A conceptual approach to the avoidance of spinal reinjury during rest. *Phys Ther* 1987;67:549–53.
19. Dolan P, Earley M, Adams MA. Bending and compressive stresses acting on the lumbar spine during lifting activities. *J Biomech* 1994;27:1237–48.
20. Kingma I, Baten CT, Dolan P, *et al*. Lumbar loading during lifting: a comparative study of three measurement techniques. *J Electromyogr Kinesiol* 2001;11:337–45.
21. Oxland TR. Fundamental biomechanics of the spine—What we have learned in the past 25 years and future directions. *J Biomech* 2016;49:817–32.
22. Adams MA, Hutton WC. The relevance of torsion to the mechanical derangement of the lumbar spine. *Spine* 1981;6:241–8.
23. Solomonow M. Neuromuscular manifestations of viscoelastic tissue degradation following high and low risk repetitive lumbar flexion. *J Electromyogr Kinesiol* 2012;22:155–75.
24. Hill S, Goldsmith J. Biomechanics and prevention of body shape distortion. *Tizard Learning Disability Review* 2010;15:15–32.
25. Waugh A, Hill S. Body shape distortion: promoting postural care at night. *Learning Disability Practice* 2009;12:25–9.
26. Murayama R, Kubota T, Kogure T, *et al*. The effects of instruction regarding sleep posture on the postural changes and sleep quality among middle-aged and elderly men: a preliminary study. *Biosci Trends* 2011;5:111–9.
27. Buchbinder R, van Tulder M, Öberg B, *et al*. Low back pain: a call for action. *Lancet* 2018;391:2384–8.
28. De Koninck J, Lorrain D, Gagnon P. Sleep positions and position shifts in five age groups: an ontogenetic picture. *Sleep* 1992;15:143–9.
29. Goldman SM. Nocturnal neuropathic pain in diabetic patients may be caused by spinal stenosis. *Diabet Med* 2005;22:1763–6.
30. Desouzart G, Filgueiras E, Melo F, Matos R, *et al*. eds. *Human body-sleep system interaction in residence for university students: Evaluation of interaction patterns using a system to capture video and software with observation of postural behaviors during sleep*. Kraków, Poland: 5th International Conference on Applied Human Factors and Ergonomics, 2014.
31. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol* 2005;8:19–32.
32. Khalil H, Peters M, Godfrey CM, *et al*. An evidence-based approach to scoping reviews. *Worldviews Evid Based Nurs* 2016;13:118–23.
33. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci* 2010;5:9.
34. Peters MD, Godfrey CM, Khalil H, *et al*. Guidance for conducting systematic scoping reviews. *Int J Evid Based Healthc* 2015;13:141–6.
35. Tricco AC, Lillie E, Zarin W, *et al*. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med* 2018;169.
36. Covidence. *Melbourne Australia: veritas health innovation*, 2018.
37. Michaleff ZA, Costa LO, Moseley AM, *et al*. CENTRAL, PEDro, PubMed, and EMBASE are the most comprehensive databases indexing randomized controlled trials of physical therapy interventions. *Phys Ther* 2011;91:190–7.
38. EndNote. *X8 ed*. Philadelphia USA: Clarivate Analytics, 2018.
39. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health* 1998;52:377–84.
40. Olivo SA, Macedo LG, Gadotti IC, *et al*. Scales to assess the quality of randomized controlled trials: a systematic review. *Phys Ther* 2008;88:156–75.
41. Korakakis V, Whiteley R, Tzavara A, *et al*. The effectiveness of extracorporeal shockwave therapy in common lower limb conditions: a systematic review including quantification of patient-rated pain reduction. *Br J Sports Med* 2018;52:387–407.
42. Cary D, Collinson R, Sterling M, *et al*. Examining the relationship between sleep posture and morning spinal symptoms in the habitual environment using infrared cameras. *Journal of Sleep Disorders: Treatment and Care* 2016.
43. Abanobi O, Ayeni G, Ezeugwu C, *et al*. Risk-disposing habits of lowback pain amongst welders and panel beaters in Owerri, south-east Nigeria. *Indian Journal of Public Health* 2015;6:332–7.
44. Centre for Evaluation and Monitoring. Effect size calculator. 2018 https://www.cem.org/effect-size-calculator
45. IBM Corporation. *SPSS statistics for Mac. 25.0 ed*. New York:USA: Armonk, 2018.
46. Field A. *Discovering statistics using IBM SPSS Statistics. 5 ed*. Los Angeles: SAGE Publications, 2017.
47. Hignett S. Intervention strategies to reduce musculoskeletal injuries associated with handling patients: a systematic review. *Occup Environ Med* 2003;60:e6–e.
48. Gordon S, Grimmer K, Trott P. Understanding sleep quality and waking cervico-thoracic symptoms. *Internet Journal of Allied Health Sciences and Practice* 2007;5:1–12.
49. Haex B. *Back and bed: ergonomic aspects of sleeping*. Boca Raton: CRC Press, 2005.
50. Gordon S, Grimmer K, Trott P. Self reported versus recorded sleep position: an observational study. *The Internet Journal of Allied Health Science and Practice* 2004;2:1–10.
51. Yu C. Why is self-report of sleep position sometimes unreliable? *Sleep and Hypnosis* 2018;20:105–13.
52. Kaplowitz K, Blizzard S, Blizzard DJ, *et al*. Time spent in lateral sleep position and asymmetry in glaucoma. *Invest Ophthalmol Vis Sci* 2015;56:3869–74.
53. Gordon S, Grimmer-Somers K. Your pillow may not guarantee a good night's sleep or symptom-free waking. *Physiotherapy Canada* 2010;63:183–90.
54. Waddell G. *The back pain revolution. 2 ed*. Edinburgh: Churchill Livingstone, 2004.
55. Atlas SJ, Keller RB, Wu YA, *et al*. Long-term outcomes of surgical and nonsurgical management of sciatica secondary to a lumbar disc herniation: 10 year results from the maine lumbar spine study. *Spine* 2005;30:927–35.
56. Friedly J, Chan L, Deyo R. Increases in lumbosacral injections in the Medicare population: 1994 to 2001. *Spine* 2007;32:1754–60.
57. Runciman WB, Hunt TD, Hannaford NA, *et al*. CareTrack: assessing the appropriateness of health care delivery in Australia. *Med J Aust* 2012;197:100–5.
58. Luo X, Pietrobon R, Hey L. Patterns and trends in opioid use among individuals with back pain in the United States. *Spine* 2004;29:884–90.
59. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Man Ther* 2005;10:242–55.
60. Gabel CP, Mokhtarinia HR, Hoffman J, *et al*. Does the performance of five back-associated exercises relate to the presence of low back pain? A cross-sectional observational investigation in regional Australian council workers. *BMJ Open* 2018;8:e020946.
61. Micheo W, Baerga L, Miranda G. Basic principles regarding strength, flexibility, and stability exercises. *PM&R* 2012;4:805–11.
62. Solomonow M, Baratta RV, Banks A, *et al*. Flexion-relaxation response to static lumbar flexion in males and females. *Clin Biomech* 2003;18:273–9.
63. Solomonow M, Zhou BH, Lu Y, *et al*. Acute repetitive lumbar syndrome: a multi-component insight into the disorder. *J Bodyw Mov Ther* 2012;16:134–47.
64. Cartwright R, Ristanovic R, Diaz F, *et al*. A comparative study of treatments for positional sleep apnea. *Sleep* 1991;14:546–52.
65. van Maanen JP, de Vries N. Long-term effectiveness and compliance of positional therapy with the sleep position trainer in the treatment of positional obstructive sleep apnea syndrome. *Sleep* 2014;37:1209–15.

Appendix 23. Abstract: Measurement of Sleep Posture in the Habitual Environment

MEASUREMENT OF SLEEP POSTURE IN THE HABITUAL ENVIRONMENT

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Question: Can valid and reliable measures of sleep posture in the habitual environment, be obtained using infrared video recording?

Design: Test-retest reliability study.

Participants: Twenty physiotherapists.

Intervention: Participants viewed the same 36 randomised, video images of sleep postures on two occasions, at least two days apart. Participants recorded each viewed posture as one of four; supine, supported side lying, quarter prone and prone. Images viewed were a mix of natural light and IR and varied bed coverings; uncovered, under a sheet, and under a sheet plus duvet.

Outcome Measures: Validity and reliability of sleep posture recordings.

Results: Validity (comparison with correct answer): mean Cohen's Kappa = 0.908, range: 0.765 – 1. Reliability inter-rater excellent: Fleiss Kappa = 0.832 (95% CI = (0.8158, 0.8446) and intra-rater was almost perfect: mean Cohen's Kappa = 0.9257, range 0.801-1, with a value of 1 for 25% of the raters.

Conclusion: Valid and reliable assessments of sleep posture in the habitual environment can be obtained using portable, infrared video recording. Data collected this way has the potential to be useful for clinical and research applications.

Key Practice Points:

- Infrared video accurately records sleep posture
- Physiotherapists are accurate and reliable when viewing standard recorded images

Appendix 24. Abstract: Do we know our Sleep Posture?

Abstract Reference 086

Cary D, Collinson R, Sterling M, Briffa K. 2014. Do we know our sleep posture and does sleep posture influence spinal symptoms? Sleep and Biological Rhythms 12 (Supplement 1, pg 23) doi:10.1111/sbr.12082

Question: Is there a difference between perceived and actual sleep postures? Is there a relationship between sleep posture and complaints of morning symptoms?

Design: Cross sectional observational pilot study. Participants: Fifteen sleeping adults were filmed using infrared video techniques. Recordings were viewed to determine actual time spent in each of four postures; prone, supine, supported side lying and ¾ prone.

Outcome measures: Participants completed a pre-sleep questionnaire in which they nominated the percentage of time they spent in each posture and the number of mornings per week they experienced pain and stiffness.

Results: ICC (95% CI) were calculated, comparing actual and predicted sleep posture; supine = 0.824 (0.482,0.940), supported side lying 0.521 (−0.526,0.842), and ¾ prone 0.485 (−0.629,0.830) and prone ICC = 0.370, 95% CI = (−0.437,0.764). Combining ¾ prone and sup-ported side lying into one side lying group, resulted in 0.742 (0.230,0.914). The time spent in different sleeping postures (expressed as a percentage of the time spent asleep) did not differ significantly according the level of morning symptoms (ANOVA p>.43). However, raw data trends indicate participants with morning symptoms (neck, back or both) spent more time in prone and less in supine and those without morning symptoms spent less time in ¾ prone and more in supported side lying.

Conclusion: Participants were able to reliably predict the percentage of the night they spent in supine but none of the other three sleeping postures. These data suggest that self-report may not be an adequate means of assessing whether sleep posture as an aggravating factor for morning pain and stiffness. In this small sample there was suggestion that sleeping in the prone and ¾ prone positions may be associated with waking with morning symptoms, however the associations were not significant and should be further examined in a larger sample.

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Title: Disruption of axoplasmic transport induces mechanical sensitivity in intact rat C-fibre nociceptor axons
Author: Andrew Dilley, Geoffrey M. Bove
Publication: Journal of Physiology
Publisher: John Wiley and Sons
Date: Jan 14, 2008

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Portion	Figure/table
Number of figures/tables	1
Original Wiley figure/table number(s)	Figure 5
Will you be translating?	No
Title of your thesis / dissertation	The Effect of Changing Sleep Posture on Spinal Symptoms and Quality of Sleep in Cervical and Lumbar Symptomatic Participants
Expected completion date	Aug 2019
Expected size (number of pages)	300
Requestor Location	AAP Eduation 5 William Street Esperance, other 6450 Australia Attn: AAP Eduation
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