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Examining the Relationship between Sleep Posture and Morning Spinal Symptoms in the Habitual Environment Using Infrared Cameras

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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.

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Conclusion: The protocol tested provided a low cost, reliable, unobtrusive and portable method to asses 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

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.**security**camera**king**.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.
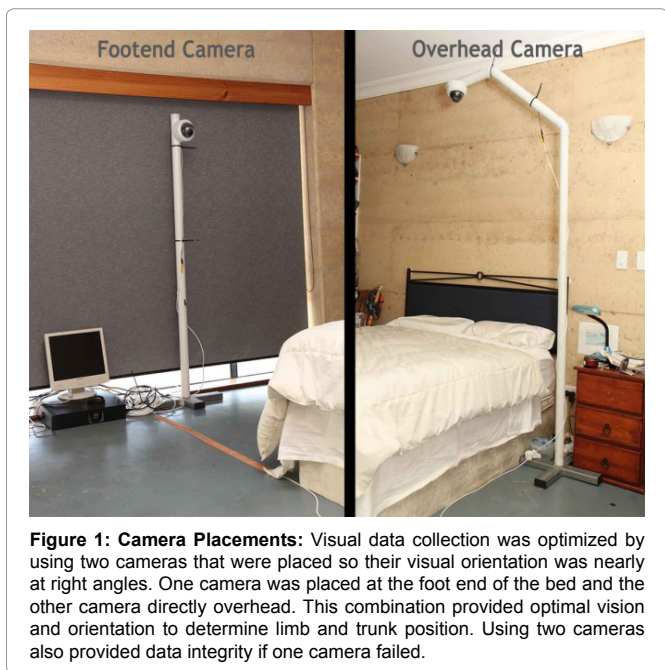
Figure 1: Camera Placements: Visual data collection was optimized by using two cameras that were placed so their visual orientation was nearly at right angles. One camera was placed at the foot end of the bed and the other camera directly overhead. This combination provided optimal vision and orientation 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
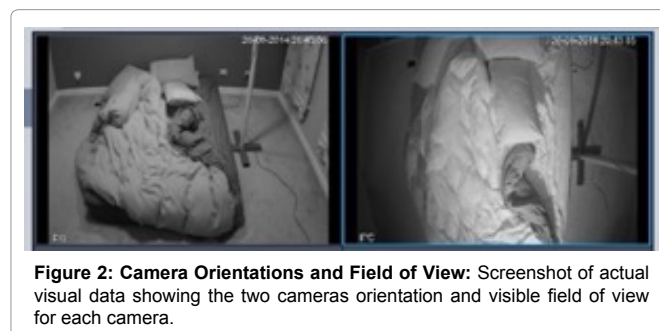
Figure 2: Camera Orientations and Field of View: Screenshot of actual visual data showing the two cameras orientation and visible field of view for each camera.

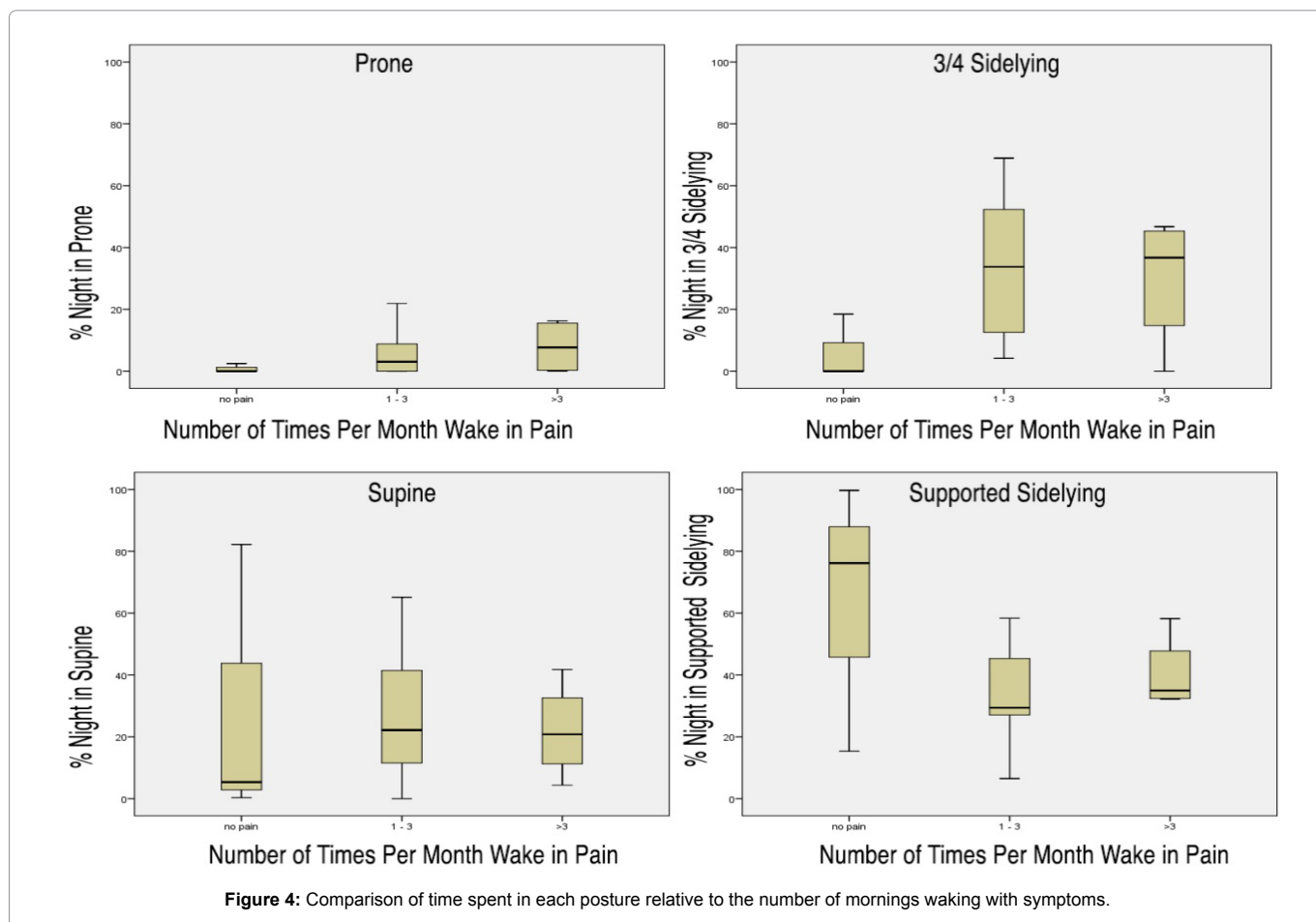**Figure 3:** Sleep Posture Classifications.

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 ¾ 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

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

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. Helmanis 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.

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 Edtn 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 Edtn, Churchill Livingstone, UK.

46. Kramer J (1990) Intervertebral Disc Diseases; Causes, Diagnosis, Treatment and Prophylaxis. 2nd Edtn, 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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