BIOMECHANICAL TESTING OF MATTRESS ZONING SYSTEMS

An Independent Report for Silentnight Group Ltd

DR AMBREEN CHOHAN, PROF JIM RICHARDS, LAURENCE SMITH
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REMIT OF THIS REPORT

This final independent report recognises the agreement established in the contract between Silentnight Group Ltd and the University of Central Lancashire (Allied Health Research Unit). This report discusses all the main outcome measures of this study including all data and meets the full contractual obligation between the parties.

INTRODUCTION

Humans spend around a third of a lifetime in bed (Gordon and Grimmer-somers, 2011), so in order to achieve improved quality of sleep it is vital to establish optimal sleeping conditions. Quality sleep is defined as when the human body is able to relax, recover and replenish itself most effectively. Research has demonstrated a direct relationship between the amount of quality sleep a person achieves, and their mood, behaviour, motor skills and overall performance in their everyday working and leisure activities (Brendel et al, 1990 & Smith and Maben, 1993 & Dotto, 1996 & Meney et al 1998 & Schlesinger et al, 1998). To allow for improved quality of sleep, sleep surfaces have several key roles, where the main function is to support the body in such a way that the muscles and intervertebral discs are able to recover from an almost continuous loaded force throughout the day (Gracovetsky, 1987). Combining gravity with the fact that humans spend a large proportion of their day in a vertical stance, whether it be standing or sitting, there is a constant load being applied to the soft tissues within the back, and as such it is important that a sleep system can alleviate this force at night. This reduction in load allows the pressure to be relieved from the intervertebral discs and surrounding musculature, therefore initiating recovery and rehydration as well as the regeneration of elasticity within soft tissues (Nachemson and Elfstrom, 1970 & Huysmans et al, 2004). Failure to achieve this state of recovery, however, can lead to the onset of back pain, and in particular simple mechanical Lower Back Pain (LBP).

In 1991, Frymoyer and Cats-Baril suggested that as much as 80% of the western population could suffer with at least one episode of disabling LBP at some stage in their lifetime. Now, LBP is said to affect two thirds of adults within the UK at some point in their lives, with as many as 2.5 million people suffering with such pain on a daily basis. A large prospective study by O'Donoghue and Fox (2009) found that there is a strongly significant relationship between sleep quality and LBP, with 55% of people reporting a restless night or very light state of sleep when experiencing an episode of LBP, compared to those that were pain free. There are however, a variety of mechanisms that are said to reduce LBP, and subsequently improve the quality of sleep including a decrease in spinal muscle activity, improved spinal alignment, and the reduction of pressure at main contact areas between the body and the sleep surface (Lahm and Iaizzo, 2002 & Verhaert et al, 2011 & Lee and Park, 2006). All of these factors can be accommodated for by varying mattress firmness, comfort layers and/or "zoning" within mattresses. A good quality sleep system will aim to adhere to as many of the aforementioned mechanisms as possible in order to provide improved comfort, and therefore improved sleep quality, to an individual.

AIMS

This study explores the effect of mattress zoning on biomechanical factors. The aims of the study are

- to explore differences in spinal alignment and pressure distribution when lying on 3 different mattresses.
- to identify any changes in muscle activity when moving on the 3 different mattresses
- to explore subjective feedback on support and comfort relative to mattress zoning

METHOD

RECRUITMENT OF PARTICIPANTS

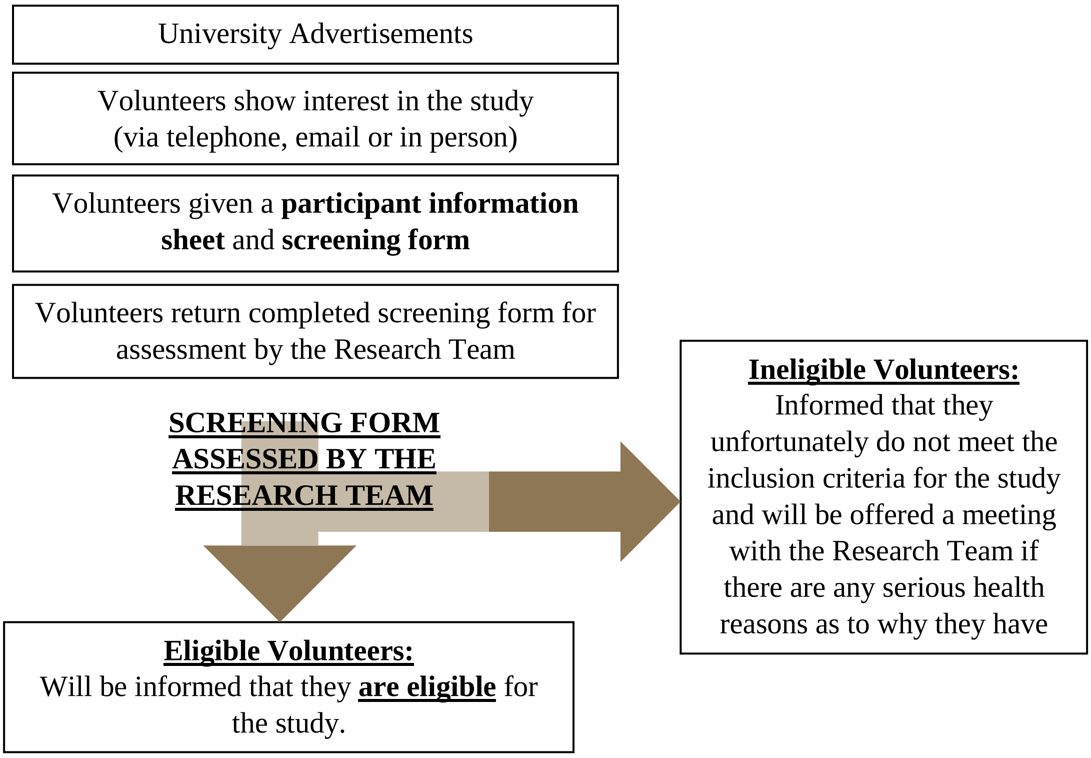

FIGURE 1. Schematic diagram representing the recruitment process

Participants were recruited (Figure 1) from within the University including UCLan staff and students through campus based advertisements and social media. Volunteers from outside the University who heard of the study through word of mouth (due the study's snowballing effects) were also included. Participants were required to actively volunteer for the study by contacting the researchers if they were interested in participating in the study using the contact information on the advertisements. Once a volunteer had shown interest in the study, they were given an information sheet to read and keep and a modified red flags screening form (Greenhalgh & Selfe, 2010) to fill and securely return. Participants were provided with the opportunity to ask the research team any questions regarding the study. All participants were required to meet the inclusion criteria stipulated; to be free from any spinal red flags, free from spinal pain, with no history of any back surgery, not currently pregnant with comfortable mobility in the spine.

Procedure

Participants were asked to visit the Allied Health Research unit (AHRu) movement analysis laboratory (Figure 2) at the UCLan campus at an arranged date and time. Upon arrival at the lab (Figure 2) participants were reminded of what the testing protocol involves. Participants were required to wear a pair of shorts for the testing protocol. Additionally, during the testing participants were required to choose between either removing their upper body clothing or wearing an adapted t-shirt with a slit along the spine to allow appropriate analysis of spinal posture (see figure 2).

Baseline Data

Participants were asked to complete a consent form in line with the ethical guidance, before being asked some baseline questions relating to preferences in sleep system and current sleep surface. Body measurements were taken including height, weight, shoulder height and width, waist to hip ratio, waist height, and hip height.

Figure 2 (Left) The AHRu movement lab (Brook Building, UCLan) **(Centre)** Adapted t-shirt for marker placement and collection of spinal data. **(Right)** Static model in software (Visual3D, CMotion, MD, (USA)).

Biomechanical Data

Small retroreflective tracking markers (figure 2) were attached to each individual using a 5 segment spinal model (adapted from: Chohan et al. 2013; Preuss and Popovic 2010) and the

Calibrated Anatomical System Technique (Capozzo, 1995) for the lower limbs and pelvis *(Further details in the results section)*. Data from the retroreflective markers was recorded using a 10 camera Oqus Qualisys motion capture system (Qualisys AB, Sweden). Participants were not identifiable in the recordings (Figure 2 RIGHT) and all recordings were coded to allow for complete anonymity. Movement data was collected using Qualisys Track Manager (QTM v.2.13; Qualisys AB, Sweden) and analysed using Visual 3D software (C-Motion, MD, USA).

In addition to the movement analysis, electromygraphic (EMG) sensors were placed bilaterally on the lumbar multifidus spinae and erector spinae longissimus muscles (Delsys, MA, USA; figure 4) in order monitor changes in muscle activity. EMG sensors were positioned in line with published guidelines (SENIAM, The Netherlands). All EMG data was synchronised to the above movement data using QTM v2.13 and Visual3D.

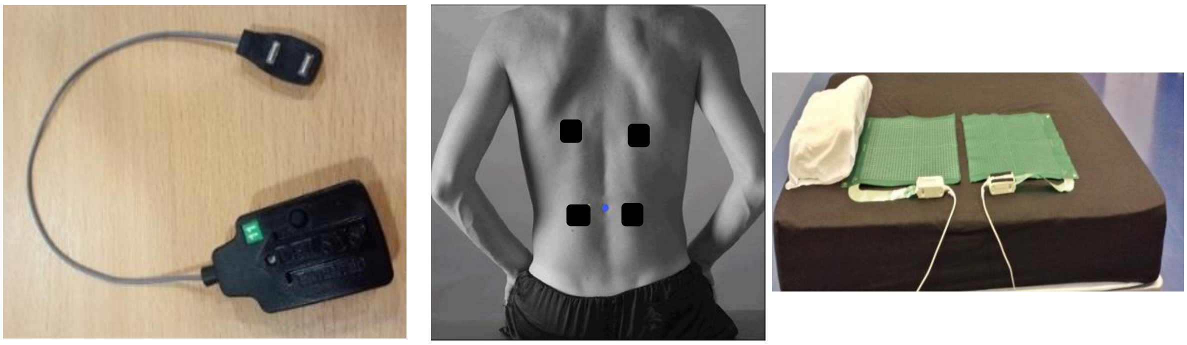

FIGURE 3 (LEFT): Electromygraphic sensors (Delsys, MA (USA)) **(CENTRE)** Positioning of EMG sensors in accordance with SENIAM guidelines. **(FIGURE 4; RIGHT)**. Conformat, Tekscan, MA, (USA)

Pressure distribution mats (Conformat, Tekscan, MA, (USA); Figure 4) were placed under the individuals' shoulder and hip, to monitor peak pressure differences between mattresses (Figure 4). The shoulder and hip were chosen based on their key role to support an individual on their sleep surface when in a side lying position. This data was collected using the Conformat Clinical software (version 7.6) and exported using FScan Research (v.6.85) for further analysis in MS Excel to allow peak pressures at the two main sites to be identified.

A static standing recording was taken, participants were positioned on a bed (standardised double divan base + one of the mattress options) in a predetermined side-lying semi-foetal position. Participants were required to remain in this side lying position for 20 minutes, during which recordings were made at various time points. At the end of this 20 minute period, participants were instructed to complete a standardized "partial-roll" on the bed. This involved straightening the legs, before then bringing the top leg over to approximately 90 degrees. This procedure was then repeated twice more on two different configurations of mattress. Mattresses were tested in a randomized order to which the participants were blinded (www.randomisation.com). The mattresses varied internally in terms of their zoning configuration (Non-zoned, Zoned, Auto-zoned), however all mattresses visually looked identical and had a standardised comfort layer (Geltex, Recticel, UK). The procedure for this study effectively lasted for 2 hours in total. Figure 6 summarises the full protocol for each testing session.

PARTICIPANT REPORTED OUTCOME MEASURES (PROMS)

Following each mattress trial, a series of short simple questions related to each of the mattresses were asked. Participants were asked to mark locations on a body chart (Figure 5) where they perceived each of the mattresses offered the most support and where the mattress lacked support. The body chart is used widely within healthcare and has been shown to be a reliable method of collating and classifying location (Lacey et al., 2003, Schierhout and Myers, 1996). In addition to this chart individuals were asked to report on their perceived overall comfort and firmness of the mattress on a VAS scale marked between zero and ten. Key anchor words were used to describe each scale (e.g. very uncomfortable – very comfortable and soft – firm). Individuals then ranked the mattress in order of preference (1st, 2nd, 3rd).

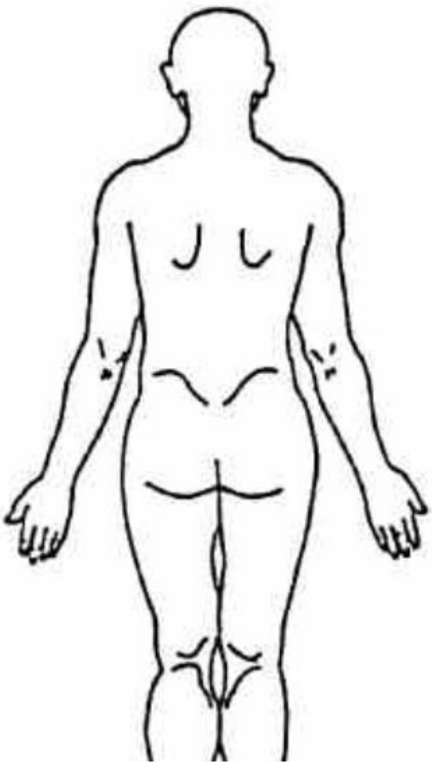

FIGURE 5 The Body Chart used to mark mattress support location.

PRE-ASSESSMENT

Volunteer asked to read participant information sheet, and complete screening form

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ARRIVAL TO MOVEMENT LABORATORY

- Participant Initial Consent taken (Appendix 3)
- Participant completes pre-testing questionnaire (Mattress type, current mattress properties, sleep issues)
- Anthropometric data measured and recorded by researchers.

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DATA COLLECTION 1 – 1st Mattress (Randomised)

- Participant positioned on the bed with a pressure mat in a standardised position beneath shoulder and hip
- Once in position, measurements occur and the participant lays still for 20 minutes
- 4 Data collections are taken at 5 minute intervals

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Mattress is exchanged for a different configuration (Randomised)

PROMs for Mattress 1

↓

DATA COLLECTION 2–2nd Mattress (Randomised)

- Repeat Data Collection 1 for 2nd mattress.

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Mattress is exchanged for a different configuration (Randomised)

PROMs for Mattress 2

↓

DATA COLLECTION –3rd Mattress (Randomised)

- Repeat Data Collection 1 for final mattress.

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Mattress is exchanged for a different configuration (Randomised)

PROMs for Mattress 3

Figure 6: Protocol Summary.

Data analysis

A preliminary analysis was performed to check whether there was any significant change over time during the 20 minute recording period on each mattress. A repeated measures ANOVA test was performed with post-hoc pairwise comparisons with *Least Significant Difference* corrections on pelvic and spinal angles, EMG and peak pressures, to analyse differences between the 3 sleep surfaces. All data was entered into IBM SPSS statistics v23 and Microsoft Office Excel 2010 for analysis. Data from questionnaires was analysed using a repeated measures ANOVA test with post-hoc pairwise comparison with LSD correction for applicable scores. The significance level was set to $p=\leq 0.05$.

RESULTS

The study has seen that twenty four individuals have contact the research team for information about the study. One individual was excluded immediately due to not meeting the inclusion criteria for the study, of the remaining participants twenty three completed the screening form to assess eligibility. Six of these volunteers were then classified as ineligible, five did not attend their scheduled appointment.

BASELINE MEASUREMENTS

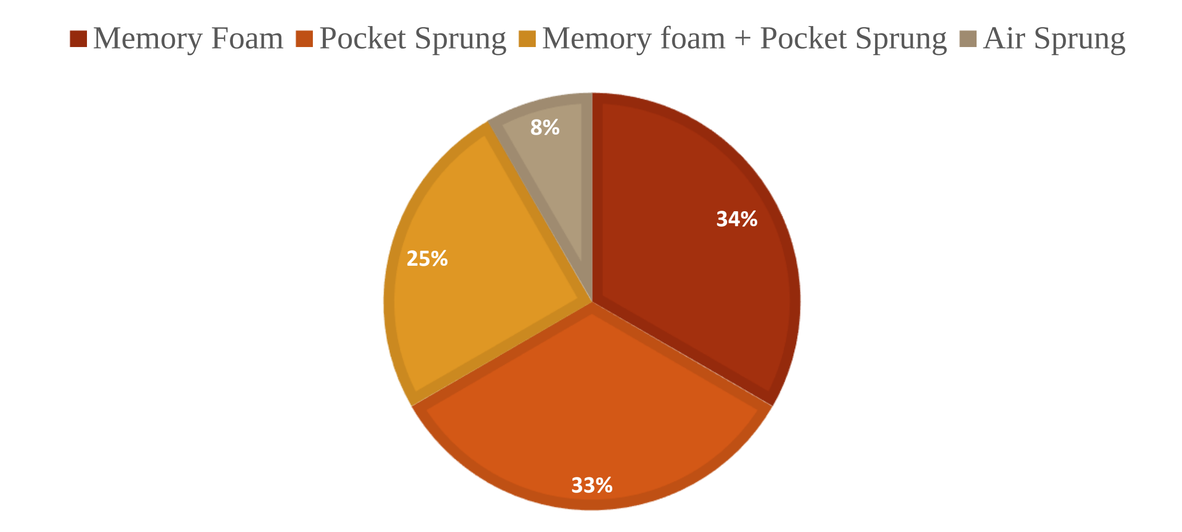
A total of (n=12) participants (mean age: 35.8 + 12.9 years; BMI: 27.2 + 6.2 kg/m2) were eligible for inclusion within this independent report. The demographic and anthropometric data of these participants are presented below (table 1).

DEMOGRAPHICS	MEAN	RANGE
Age (years)	35.8	24 -55
Height (m)	1.7	1.51 – 1.84
Weight (kg)	77.8	59 – 139
BMI (kg/m^2)	27.2	20.9 – 41.9
Shoulder Height (cm)	144.1	136.2 – 154
Shoulder Width (cm)	46.5	36 – 58
Waist Height (cm)	114.2	104 – 123
Waist Circumference (cm)	91.1	76.2 – 117
Hip Height (cm)	91.0	81.3 – 100
Hip Circumference (cm)	106.4	88.3 – 125.3
Waist Hip Ratio	0.85	0.79-0.97

TABLE 1: DEMOGRAPHICS AND ANTHROPOMETRICS OF PARTICIPANTS.

Participants reported their usual sleep surface properties (Figure 7), with the majority usually sleeping on a Memory foam ± pocket sprung mattress. Other options were given however aside from a single individual reporting an Airsprung mattress, results unanimously supported the use of the most commonly available mattress types. Though average mattress firmness and ideal mattress firmness is reported in figure 7, this indicates that on average 75% (58% wanted more, 17% wanted less) of individuals were not satisfied with the support their existing mattress provided.

Though previous research has discussed in detail the basis of sleep zoning and relative support, participants were asked about their perceptions on where their sleep surface provided support and how their ideal sleep surface would support them. Results indicated that current sleep surfaces performed best in supporting the shoulder (67%) and hip (58%). However, when describing their ideal sleep surface support 50% of individuals selected the hip and 42% selected the back as key areas that they required support with little consideration given to the shoulder.



Current sleep system	Mean	Standard Deviation
Current Mattress Firmness	5.85 (Medium)	2.05
Ideal Mattress Firmness	6.68 (Medium-Firm)	1.74

Figure 7: Usual sleep surface attributes

Biomechanical measures

Spinal analysis

Dividing the spine into five segments for analysis (upper thoracic to mid-thoracic, mid-thoracic to lower thoracic, lower thoracic to upper lumbar, upper lumbar to lower lumbar and lower lumbar to pelvis) movement data was processed between these segments using Visual 3D v.6 (C-Motion, USA). The influence of each mattress on spinal posture was assessed by initially placing each participant in their natural neutral standing posture, and classing this stance as "zero". The change in angle between each of the spinal segments away from their neutral posture was determined in order to depict which mattress had the most adverse effect on spinal alignment. The closer the degree of change was to zero, the closer the participants were to neutral alignment. Using this particular model to measure in six degrees of freedom, the sagittal (Anterior-Posterior flexion and extension), coronal (mediolateral flexion and extension), and transverse (rotational) planes of movement were analysed. Data for each segment and in each plane of movement is reported in Table 2.

Angle (Degrees °)	Mattress		
	Non-Zoned	Auto-Zoned	Zoned
Anterio-Posterior plane			
UT-MT	13.23 (±8.3)	13.17 (±8.6)	12.83 (±7.4)
MT-LT	-2.78 (8.5)*	-0.17 (±7.8) *	-0.99 (±7.5) *
LT-UL	0.68 (±6.7) *	1.38 (±7.5) *	0.45 (±6.4) *
UL-LL	-14.95 (±9.1)	-14.92 (±8.6)	-13.80 (±7.8)
LL-PEL	-0.39 (±6.1)	-0.72 (±6.5)	-0.35 (±5.4)
Medio-lateral plane			
UT-MT	-1.24 (±3.8) *	-0.68 (±3.9) *	-0.46 (±3.1) *
MT-LT	2.78 (±4.1)	2.12 (±3.0)	2.29 (±2.9)
LT-UL	3.29 (±2.9) *	2.85 (±2.9) *	2.94 (±2.9)
UL-LL	0.54 (±5.5)	1.28 (±4.9)	0.34 (±3.8)
LL-PEL	6.03 (±3.3)	5.36 (±3.4)	5.39 (±3.7)
Rotational Plane			
UT-MT	5.21 (±5.9)	4.33 (±7.0)	5.44 (±5.0)
MT-LT	1.63 (±4.2)	1.26 (±3.9)	1.81 (±4.1)
LT-UL	0.31 (±2.4)	0.48 (±2.5)	0.87 (±1.7)
UL-LL	-2.89 (±4.3) *	-4.1 (±3.3) *	-3.96 (±3.3) *
LL-PEL	1.59 (±4.7) *	1.1 (±4.4) *	0.69 (±4.4) *

Table 2: All spinal data (UT = Upper Thoracic; MT=Mid Thoracic; LT=Lower Thoracic; UL=Upper Lumbar; LL=Lower Lumbar; Pel=Pelvis. *denoting significance level of p≤0.05.

Coronal plane (Mediolateral or side to side flexion)

During the testing procedure all participants were laying on their left side, therefore a positive increase in flexion of the segment would represent either the subject raising their head and feet, or, more realistically, the increase in flexion would be caused due to a less supportive sleep surface, possibly causing "hammocking". Conversely, a negative change from neutral would suggest that the head and feet are further sunken into the mattress than the middle of the torso.

In the coronal plane there was a statistical significance of p=0.025 displayed as a main effect within the Upper Lumbar to Lower Lumbar (UL-LL) segment of the spine, demonstrating significant change in the lumbar spine between the three sleep surfaces. Pairwise comparisons indicate the greatest statistical significance (p=0.012) was seen between the Auto-zoned (AZ) mattress (1.275° of change from neutral) and the Zoned (Z) mattress (0.347° of change from neutral). In this case (AZ vs Z), the increased change from neutral seen within the AZ mattress would suggest a greater deformity of this mattress and therefore it could be assumed that the Z mattress is more supportive at the lumbar region of the spine. This finding would support the features of the zoned mattress design. Between the Non-Zoned (NZ) mattress vs the AZ mattress in significance of p=0.019 was noted (Table 2). Similar to the Z mattress, the NZ mattress demonstrated a reduced hammocking effect or assumed increase in support around this area of the spine. There was no significant difference between the performance of the Z and NZ mattresses (p=0.624) however suggesting the zone had little impact on support when compared to the non-zoned mattress.

Within the remainder of the segments, there were no statistically significant main effects of the mattress type on spinal posture within the coronal plane, however there were several significant results within the pairwise comparisons. Within the Upper thoracic to Mid-thoracic (UTMT) segment there was a significant difference (p=0.015) between the AZ and NZ mattress as well as between the Z and NZ mattresses (p=0.038). With the NZ demonstrating the greatest change from neutral. Due to the change from a neutral position being a negative value in all of these cases, this could possibly suggest that the mattresses are too firm around the shoulder area and therefore not allowing the shoulder to sink into the mattress enough which in turn may lead to the head dropping down into the pillow. Overall, results considering the coronal plane show that there is distinctly less variation from a neutral posture within the AZ mattress compared the other two mattresses.

As with the UTMT segment, the lower thoracic to upper lumbar (LT-UL) segment also demonstrated statistical significances between mattresses. There was a reduced deviation away from a neutral stance seen in the AZ mattress (2.856°) compared to the NZ mattress (3.293°), suggesting there was significantly less deviation at the LT-UL (p=0.036) within the AZ. A similar result was seen within the pairwise comparison for the Z vs NZ whereby the Z mattress demonstrated significantly less deviation than the NZ mattress (p=0.024; Table 2).

Finally in the coronal plane, there was a significant difference (p=0.014) between the AZ and NZ mattress within the lower lumbar to pelvis (LL-PEL) segment of the spine. Greater alignment was seen when using the AZ mattress as there was only a change from neutral posture of 5.365°, as opposed to 6.029° of change within the NZ mattress.

TRANSVERSE PLANE (ROTATION)

The transverse plane demonstrated its only significant findings within the lower half of the spine, initially demonstrating a very strong main effect of p=0.004 at the ULLL segment. Furthermore, pairwise comparisons reveal an extremely strong statistical relationship between the AZ and NZ mattresses (p=0.000). The NZ mattress allowed for significantly less rotation away from a neutral stance (-2.888°) compared to that of the AZ mattress (4.051° of change from neutral). Similarly, the NZ mattress significantly (p=0.016) reduced rotation at the ULLL segment when compared against the Z mattress. Both of these results suggest that within the lumbar section of the spine, the NZ mattress is superior for maintaining close-to-ideal spinal alignment. It is however possible due to the variance in these findings that other factors (e.g. anthropometrics) may have influenced the rotational posture at this particular area, for that reason further work is warranted to increase sample sizes.

Conversely, whilst the LLPEL segment of the spine also demonstrated a main factor statistical significance of p=0.018, in this area of the spine the NZ mattress displayed least resistance to rotation, deviating from a neutral stance by 1.588°. Statistically, there was significantly less rotation (P=0.012 and 0.688° of change from neutral) in the Z mattress when matched against the NZ, and a very near significance (p=0.051) between the AZ and NZ, with the AZ mattress affording less rotation.

SAGITTAL PLANE (ANTERIOPOSTERIOR FLEXION – EXTENSION)

Of the five sections of the spine there was an overall statistically significant effect shown in the mid-thoracic to lower thoracic (MT-LT) segment of the spine (p=0.034) across the three sleep surfaces. Pairwise comparison results suggested that there was a significant difference (p=0.013) between the AZ mattress and the non-zoned mattress. The AZ mattress demonstrated a change in segment angle of -0.177° from neutral, compared to -2.781° in the NZ mattress. From these results it is possible to infer that the AZ mattress significantly reduces misalignment MTLT segment of the spine in comparison to the NZ, therefore improving thoracic spinal posture.

There was also a near significant (p=0.059) pairwise comparison between the AZ and Z mattresses (-0.177° change from neutral, and -0.988° change from neutral respectively; Table 2). Though not statistically significant, it may be possible to infer therefore an improvement in performance within the AZ over the Z mattress, however an increased sample size would be required to support this theory with confidence. There were no significant differences seen between the Z and NZ mattress (p=0.115).

Within the sagittal plane there was a strong statistical significance shown within the LTUL segment of the spine between surfaces (p=0.027). Pairwise comparisons showed a strong statistically significant difference (p=0.008) between mattresses AZ and Z, as well as AZ and NZ mattresses (p=0.039). As shown in Table 2, this aforementioned change relates to a greater amount of flexion away from the neutral position when using a AZ mattress. Nevertheless, there could be a means to propose that this is actually a positive benefit to sleeping posture, as this posture affords reduced lordosis. Some previous research has suggested that greater than normal lordosis can lead to lower back pain when sleeping (Sousa et al, 2015 & Christie et al (1995). With such factors in mind excessively gliding facet joints may cause augmented pressure on intervertebral discs, and subsequently nerve endings, and in turn this inhibits the recovery, rehydration and elastic regeneration of the soft tissues (Nachemson and Elfstrom, 1970 & Huysmans et al, 2004). Additionally, excessive lordosis can cause the muscles of the lower back to shorten and the hamstrings to be elongated, therefore increasing strain the subsequent risk of lower back pain. Further work however is required to truly establish this and to ascertain whether zoning of mattresses may influence back pain long term.

ELECTROMYOGRAPHY (EMG)

Electromyography (EMG) data was analysed using both rectified (converts all negative EMG signals to positive) and integrated EMG (the area under the curve of the rectified EMG, or in other words, the total muscle activity for a given period). Results are presented in Table 3. There were no statistically significant results across any of the mattresses, however it is hypothesised that more meaningful outcomes will be seen when adjusting the comfort layer on the spring unit as it is this layer that would essentially counteract micro-movements.

EMG (µV)	MATTRESS		
	NON-ZONED	AUTO-ZONED	ZONED
RECTIFIED LEFT ERECTOR SPINAE	0.000058	0.000043	0.000059
RECTIFIED RIGHT ERECTOR SPINAE	0.000014	0.000016	0.000018
RECTIFIED LEFT MULTIFIDUS	0.000590	0.000732	0.000504
RECTIFIED RIGHT MULTIFIDUS	0.000132	0.000012	0.000108
INTEGRATED LEFT ERECTOR SPINAE	0.000041	0.000042	0.000050
INTEGRATED RIGHT ERECTOR SPINAE	0.000024	0.000026	0.000028
INTEGRATED LEFT MULTIFIDUS	0.000239	0.000228	0.000162
INTEGRATED RIGHT MULTIFIDUS	0.000081	0.000034	0.000086

TABLE 3: ALL EMG DATA

PEAK CONTACT PRESSURE

All data for peak contact pressure calculated at the shoulder and hip on each of the three sleep surfaces is reported in Table 4.

	MATTRESS		
Peak Pressure (KPa)	NON-ZONED	AUTO-ZONED	ZONED
Shoulder Peak Pressure	2.68 (0.88)	2.59 (0.86)	2.76 (0.89)
Hip Peak Pressure	2.63 (1.01)*	2.51 (0.76)*	2.92 (1.22)*

TABLE 4: ALL PEAK CONTACT PRESSURES *denoting significance level of $p \leq 0.05$.

SHOULDER

There were no statistically significant effects relating to peak pressure at the shoulder as a result of the three sleep surfaces. There were also no significant pairwise comparisons between the AZ, Z and NZ mattresses, suggesting similar performance (2.59kPa-2.76kPa).

HIP

The effects of the three sleep surfaces lead to a strong statistical significance on peak pressure at the hip ($p=0.006$). This suggests that there is a measurable difference between each of the trials. Pairwise comparisons further supported this, as there was a strong significant difference noted (p=0.004) between the AZ and Z mattresses. There was a similar level of significance between the Z and NZ mattresses (p=0.004). With this in mind, it can then be deduced that the AZ mattress demonstrated the lowest peak pressure at the hip of 2.51kPa, ahead of the NZ and Z mattresses (2.63kpa and 2.92kpa respectively) and therefore has the ability to disperse pressure more effectively.

PARTICIPANT REPORTED OUTCOME MEASURES

MATTRESS PROPERTIES

	MATTRESS		
VAS (0-10)	NON-ZONED	AUTO-ZONED	ZONED
Mattress Comfort	7.2 (2.1)	7.5 (1.97)	7.6 (1.97)
Mattress Firmness	6.5 (1.84)	6.8 (1.34)	7.2 (1.62)
Mattress Preference	1st (25%) 2nd (17%) **3rd (58%)**	1st (17%) **2nd (58%)** 3rd (25%)	**1st (58%)** 2nd (25%) 3rd (17%)

TABLE 5: MATTRESS PROPERTIES AND PREFERENCE

As mentioned earlier, following each mattress trial all participants were asked to complete a VAS scale on mattress firmness and comfort. No significant difference was seen between mattresses when considering mattress comfort, though the AZ and Z mattresses were largely similar. The zoned mattress was perceived to be the most firm, with the AZ and NZ mattress following behind closely, making the difference between them not statistically significant. It is possible from these results to suggest that there may have been no significant difference seen due to the controlled comfort layer that was within all 3 mattresses. Further work is needed to determine the effect a comfort layer has on the tested variables as it is well known how certain comfort layers may compress or degrade over time. All participants were asked to rank the three sleep surfaces in order of preference (See table 5). Of the participants, 58% ranked the zoned mattress as their most preferred, followed by the Auto-zoned and then the non-zoned.

Additional feedback was provided on each mattress by the individuals which is transcribed in Table 6. Whilst there was some positive comment passed there were numerous individuals that complained of pressure build up on the non-zoned mattress in particular. The least negative comments relating to pressure build up or other discomfort, occurred for the Auto-Zoned mattress. Contrastingly only 2 participants commented positively on the Non-Zoned Mattress, as the majority had experienced pain or discomfort such as pins and needles.

Mattress		
Non-zoned	**Auto-zoned**	**Zoned**
Too soft **for knee position, lower knee started to hurt a little because of the mattress being too soft.**	Uncomfortable on the shoulder	**Build up of pressure** on left shoulder
12 mins into testing Numbness down left arm radiating towards fingers, uncomfortable, too soft **in the rib cage and not able to breathe freely.**	No discomfort or pressure build up experienced	Able to breath freely with no pressure build up.
Knees felt pressure build up red marks **on medial aspects of knee.**	**Knees felt pressure**	No pressure points
Very Comfortable	**Some build up of pressure around the shoulder and pins and needles in hand,** but not much later than mattress NZ	**Build up of presure on left shoulder**
Build up of pressure **around the shoulder,** pain in shoulder and elbow. Pins and needles **in left hand very quickly which lasted most of the time.** Twitching in ring finger, **head felt much higher.**	Comfortable but difficult to assess firmness when lying still for 20 minutes. Easier to assess firmness on this mattress when moving positions (in my opinion).	Slightly too firm around the shoulder, no pain but **wouldn't be able to lay on it for too much longer in this position.**
I got pins and needles in the arm underneath me which didin't occur on Mattress AZ **(Mattress name added for clarity)** .	No excess pressure or discomfort	the shoulder/trunk in contact with the mattress was colder than other
No build up of pressure.	No build up of pressure	Better pressure distribution than AZ (Mattress name added for clarity) and more comfortable. No excess pressure or discomfort
discomfort and excess pressure in left hip **and shoulder. Easier to move position compare to the other 2 mattresses.**	**Too much pressure in shoulder**, hip area was soft and felt like it was sagging.	Mattress felt firmer and no build up of pressure
Much more even spread of pressure **than AZ, still slightly too firm in the shoulder.**		**initially most comfortable, but pressure built up in shoulder.** This may have been due to the fact It was the final mattress. **More achey back when got up.**
Build up of **pressure in shoulder**		no pressure points

Table 6: All mattress feedback

SUMMARY

On reflection, the results reported from this study suggest an association between the peak pressure at the hip and the spinal biomechanics at the UL-LL and the LL-PEL segments within the coronal plane. There is a logical reason to assume that a surface that disperses pressure more evenly is subsequently less firm, or less supportive as a trade-off. This is evident within the UL-LL segment of the spine, whereby there was a statistically greater change of spinal alignment away from neutral due to surface "hammocking" theory suggested to be occurring within the AZ mattress, compared to that of the Z and NZ mattresses. However, rotational spinal alignment at the LL-PEL deviated from neutral by a smaller amount within the Z compared to the other mattresses. Previous research findings (Chohan et al., 2014) have show small changes that occur at the lower lumbar to pelvic region may be beneficial to those with simple mechanical low back pain, as they become less *at risk* of torsional injuries during sleep.

All mattress variables have been ranked using a points based system (3, 2, 1) in order to give an overall score per mattress. Higher scores indicate the best performance.

VARIABLE	NON-ZONED	AUTO-ZONED	ZONED
Mattress Firmness	1	2	3 (Most firm)
Mattress Comfort	1	2	3 (Most comfortable)
Mattress Preference	1	2	3 (Most preferred)
Spinal posture	2=	2=	3 (Closest to neutral
Peak Pressure	2	3 (lowest peak hip pressure)	1
TOTAL	**7**	**11**	**13**

TABLE 7: MATTRESS SCORING

Due to the sample size of the current data set it is not possible to allude to further changes that may occur in biomechanical parameters between individuals of varying body sizes and the "ideal sleep system". However, it is clear that changing a single variable (the type of zoning) can clearly affect an individuals' wellbeing by potentially putting them in a more "at risk" posture. It has long been suggested a multifactorial approach is required when designing the ideal sleep system as one style/size doesn't suit all, this research clearly show the need to consider multiple factors. Though the Zoned mattress performed will in terms of spinal alignment, the Auto-zoned mattress appeared to dissipate surface pressure better. Further research is needed to explore the interaction between the zoning and comfort layers to be able to truly comprehend the potential benefits this could provide the end-user.

KEY HIGHLIGHTS

- **SPINAL ALIGNMENT:** In medial-lateral plane, the Upper Lumbar to Lower Lumbar segment of the spine, demonstrate a significant change in the lumbar spine between the three sleep surfaces. Zoned Mattress demonstrated least change from neutral and possibly less *hammocking* of the mattress. In the Rotational plane, there was significantly less rotation in the lower lumbar to pelvic area in the Zoned and Auto-Zoned mattress compared to the Non-Zoned mattress. This finding has the potential to give benefits to individuals with sleep associated back pain.
- **SURFACE CONTACT PRESSURE** – The Auto-Zoned mattress demonstrated the lowest peak pressure at the hip of 2.51kPa, ahead of the Non-zoned and Zoned mattresses and therefore has the ability to disperse pressure more effectively. This would ordinarily lead to the assumption that the Auto-zoned mattress performed superiorly. It is suggested that in line with the above spinal alignment data, an increase in pressure may actually be directly attributed to mattress support or firmness. The further testing of various comfort layers could help to further explore this.
- **PARTICIPANT REPORTED OUTCOME MEASURES** – Whilst on average the Zoned mattress was perceived to be the most firm and comfortable and preferred mattress, results indicated no trend towards significance, so would be deemed to be difficult to differentiate. This is possibly due to the standardisation of the comfort layer, masking the change in spring configuration.
- **OVERALL:** A zoned mattress outperforms a non-zoned mattress in several significant areas, both objectively and subjectively. Whilst some benefits are noted in the Auto-Zoned mattress, it is suggested through overall multifactor analysis, the Zoned mattress is marginally superior. However, as the Auto-zoned mattress still distinctly outperformed the Non-zoned mattress, it warrants further possible development as a potential future alternative.

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