DOHRMANN CONSULTING

Australia's leading safety and ergonomics experts

Our Ref: BFB Q131 EPR6 (product assessment) R3

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Mr Mario Piraino
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Dear Mario,

Ergonomics Product Assessment

Thank you for inviting our firm to undertake an independent ergonomics assessment of some of the bed designs currently available on the market, including the three types of beds from the *Ergonomic Life International* range. Here is our report.

We received considerable assistance during our consultations and at the inspection from a number of people, including yourself. Thank you. Please pass on our thanks to the staff involved, including Peter Ridsdale and Peter Scroggie.

If you have any questions about the report, or if you need any further information or clarification, please contact us.

Yours faithfully,

Bill Contoyannis
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Ergonomics product assessment:

Review of bed/mattress designs

for

Ergonomic Life International

Dohrmann Consulting
consulting engineers and ergonomists
October 2016

Contents

Executive summary

Dohrmann Consulting (ergonomics and safety consultants) were engaged by Ergonomic *Life International* to provide an independent opinion regarding the ergonomic characteristics a bed/mattress product should possess, and to undertake an independent ergonomics assessment of a range of designs.

Based on ergonomic principles, a bed/mattress system should provide a body support surface which allows the musculoskeletal structure (bones and joints) and in particular the spinal column, to adopt a neutral position. When the joints of the body are in a neutral position the static load is minimised, ensuring that additional and/or unnecessary strain on joints can be avoided.

Pressure on specific parts of the body can be reduced in side lying by additional support at the waist and in supine (on the back) lying by additional support at the lumbar section of the spinal column. The increase of support at the waist will also reduce the strain within the spinal column. A lack of support in this region will increase the stresses on the spinal column. Uniform support on a contoured surface, matching the body's natural shape, would provide well distributed pressure support across the body.

For a bed to conform with these fundamental ergonomic principals, it is hypothesised that a bed must deflect less at the waist/lumbar region, when compared with the deflection at the shoulders and hips.

This ergonomic assessment is based on supporting an "ideal" lying posture, which is considered a posture that allows a neutral position of the spinal column to be maintained. In side-lying this means that the spinal column remains straight, and in supine (on the back) lying, it maintains the natural S-curve. As seen in Figure 3 and Figure 4.

This curve needs to be matched by the deflection of the bed/mattress system when supporting a body lying on the system. Most of the bed/mattress products assessed provided some level of variation, to a greater or lesser extent, that matched the anthropometric curve, supporting the waist or lumbar contour however the adjustable bed/mattress products were much closer to the desired ergonomic criteria.

Based on this assessment, the ergonomic principles of a neutral position of the spinal column, thus reducing the strain, is ideally achieved through a bed/mattress system which can be adjusted to accommodate the variation of weight as well as the shoulder, waist and hip dimensions of each individual. This adjustment should also be applied to each side of the bed. Two of the ErgoLife products achieved this.

Background

Dohrmann Consulting (ergonomics and safety consultants) were engaged by *Ergonomic Life International* to provide an opinion on the ergonomic characteristics a bed should possess, and to undertake an independent ergonomics assessment of a range of bed designs. The ergonomics assessment of the products was to take into account the following -

- Product Design – performance and benefits assessment;
- User – the range of people expected to use the product (anthropometry); and
- Use of the product – how it is used (ergonomics – human engineering).

This report now sets out the results of that assessment.

Human size variations - anthropometry

The relevant dimensions of parts of the body in side lying and in supine lying are the measurements considered in this assessment. These dimensions; the shoulder, waist, hip and curvature of the lower back were obtained from recognised arthrometric data sources.

The anthropometric data are set out in the authoritative publications of PeopleSize and Humanscale.

PeopleSize[1] data was used for the required dimensions and ranges of a population of 1st to 99th percentile of Australian adult males and females. These dimensions guided the setup of a testing device and procedure. This range has been chosen to accommodate for the majority of individual variations, including body variations between males and females. Some of the available dimensions within the software are demonstrated in the figure below.

1 *PeopleSize* (Friendly Systems, 2008, Loughborough, England)

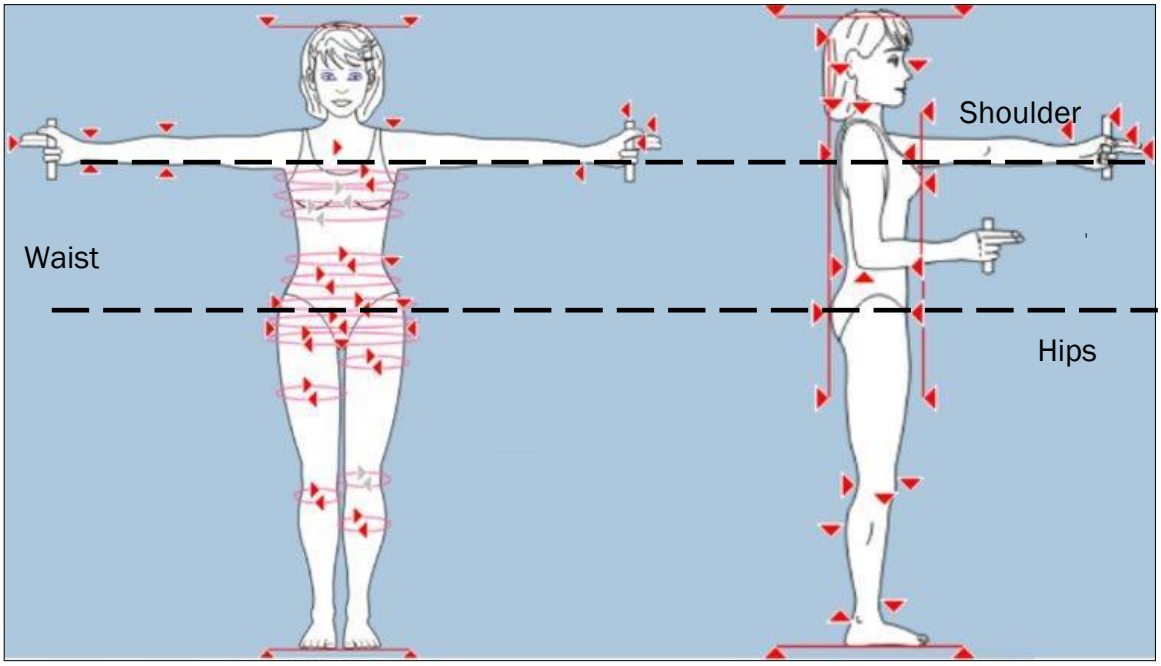

Figure 1 – Anthropometry from PeopleSize

Additional dimensions were also set out in the authoritative publication, Humanscale[2], which outlines some of the dimensions used to guide this assessment.

This data determined the common distance between the mid-shoulder, waist and hip region of the torso for the Australian adult population. For the purpose of these tests the distance between both the mid-shoulder and waist, and the waist and hip region of the torso was fixed at 200 mm. These dimensions are further supported by Nordin and Frankel[3].

For the purpose of these tests the location of the lumbar curve and the waist are considered the same location in supine and side lying, respectively.

Other relevant guidance material included the weight of each body segments of the torso. As per the table below, Plagenhoef et al 1983[4], research was used to determine the weights for specifically; the thorax (shoulders), lumbar (waist) and pelvis (hips) segments.

Note: The weight of the arms was not added to the weight of the shoulder region for the purpose of this study.

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[2] Diffrient, N et al, *Humanscale 1/2/3 and Humanscale 4/5/6* The MIT Press, 1981, Cambridge, Massachusetts

[3] *Basic Biomechanics Of The Musculoskeletal System*, Margareta Nordin and Victor H. Frankel, third edition, 2001 Lippincott Williams & Wilkins.

[4] http://www.exrx.net/Kinesiology/Segments.html

Table 1 -Weights of body segments

Body Segment - percentage of total body weight	Males (%)	Females (%)
Thorax (shoulders)	20	17
Lumbar (waist)	13	13
Pelvic (hips)	13	16
Total percentage of body mass of the torso	46	46
Total per leg	17	18
Total per arm	6	5
Head	8	8

The location of the middle of each of the three segments of the torso was measured as; top of arm pit for the shoulder segment, belly button for the waist segment and C7 for the pelvic/hip segment.

Products assessed

The consultants (biomechanical and rehabilitation engineers Bill Contoyannis and Kristen Morris) made an inspection at the South Melbourne showroom on 7 October 2016. Six bed types were examined, operated, measured and assessed, three conventional products and three ErgoLife products.

The three ErgoLife products have been designed by Mario Piraino with the aim of provide sleeping surfaces for people of varying body mass, shape profiles and sleeping positions. They aim to allow the spinal column to adopt an unstrained, neutral position, during sleep.

All of these bed/mattress products are intended for use by two people (no single bed/mattress products were considered).

Each of the conventional bed/mattress types underwent a comparative analysis against three products from the ErgoLife range. All of these products are listed in the table below.[5]

The ErgoLife Zero Stress system and 9 zone ErgoLife Contour can both be adjusted separately on each side of the bed.

Table 2 – bed/mattress products for comparison

Conventional Product	ErgoLife Product
5 Zone Pocket Spring	9 Zone ErgoLife Contour
Traditional Bonnell Spring Mattress	ErgoLife Active Mattress
Latex Mattress on an ErgoLife Zero Stress system with no adjustments	Latex Mattress on an ErgoLife Zero Stress System appropriately adjusted

[5] See also: Appendix – Bed Types

Consultation also occurred during the visit with Peter Ridsdale and Peter Scroggie.

The following additional documentation has also been examined:[6]

- Application of the scientific principles in supporting the human body by Mario Piraino;
- The study of posture and pressure on the human form on comparative bed types by Noel Lythgo 2005;
- The study of bed construction and the dynamic impact on the human form;
- Pressures produced/reduced by mattresses and toppers on a human body laying on a bed, by Mario Piraino;
- The effects of the "Spinal Support Bedding System" on recumbent postures, using Computer Radiography, pressure mapping and outcomes assessment questionnaires, conducted by researchers from the School of Chiropractic at Macquarie University Sydney, led by Dr. Ray Hayek, dated 4 November 2007; and
- Mattress design – the history, by Mario Piraino.

[6] These documents are available from Ergonomic Life International

Ergonomics Assessment Criteria

Based on ergonomic principles, a bed/mattress system should provide a body support surface which allows the musculoskeletal structure (bones and joints) and in particular the spinal column, to adopt a neutral position. When the joints of the body are in a neutral position the static load is minimised, ensuring that additional and/or unnecessary strain on joints can be avoided.

Renowned text authors Nordin and Frankel[3] discuss the properties of a bed as follows;

> *'A good bed should (1) adapt to body curvatures, (2) remain 'flat'* (i.e. not sink in the middle)*, (3) have a pleasant spring action, (4) have good ventilation, and (5) not be too warm or too cold. Aspects 1 to 3 concern body support that evenly spreads the pressure on protruding (bony) parts, gives a straight spine when lying on the side, and gives a natural S-shape to the spine in the supine posture. Lying on a horizontal surface is special because each body part receives separate support with minimal pressure on skin, and under-lying tissues and joints can be kept in a relaxed position. The results must be that for static equilibrium, muscle action is superfluous.'*

The assessments used in this report were limited to items 1-3 above.

Pressure on specific parts of the body can be reduced in side lying by additional support at the waist and in supine (on the back) lying by additional support at the lumbar spinal column. The increase of support at the waist will also reduce the strain within the spinal column. Uniform support on a contoured surface, matching the body's natural shape, would provide well distributed pressure support across the body. This can be seen in the pressure mapping research shown in Appendix B.

The assessment conducted here is based on the aforementioned ideal posture in sleep, which is with a neutral spinal column. In side-lying this means the spinal column remains straight and in supine lying, it has the natural S-shape.

The size and position of the human torso affects the spinal column's position. The deflection of the surface upon which the body lies (i.e. the bed/mattress) also affects the position of the spinal column. As such, testing was done for the three sections of the torso; shoulders, waist and hips.

The spinal column is uniformly supported (i.e. is straight) in side lying when the surface deflects sufficiently to allow natural curve between the shoulders, waist and hips.

Thus the surface needs to deflect at the shoulders and hips to allow for more uniform support to be provided at the waist. Similarly, with back lying, the lumbar curve should be supported. To allow for lumbar support, the shoulders and hips should 'sink' further into the support surface.

For the purpose of these tests, the deflection under load of the surface should match the weight of the body segment (force being applied to the surface) as well as the curve shape along that part of the body.

Methodology

Each bed surface was loaded with circular weights with a 190 mm diameter, as per the weights specified below. The test was completed for a range of the population from a large male to a small female, based on the anthropometric data. These are; 100 kg male (95 %ile Australian adult male) and a 50 kg female (5 %ile Australian adult female).[7]

Table 3 – Body segment weights for test subjects

Body Segment weight	100 kg Male	50 kg Female
Thorax (chest)	20kg	8.75kg
Lumbar (waist)	13.75kg	6.25kg
Pelvic (hips)	13.75kg	7.5kg

This methodology assumes that the shape required to support the spinal column in a neutral position would not be influenced by the mass of the head and legs. However, it is noted that the overall mattress deflection would be increased by this additional mass for an adult body in lying.

The weights were placed 40 cm in from the side of the bed and at a set distance of 60 cm, 80 cm and 100 cm from the head of the bed. These distances represented the common distance of 20 cm between the mid-shoulder, waist and hip region. This allowed for a distance of 40 cm from the top of the head to the centre of mass of the shoulder segment, and 20 cm clearance from the top of the bed to the top of the head.

The diagram below shows the location of the three circular weights, with a 20 cm diameter forming the centre of mass, for the three sections representing the adult torso.

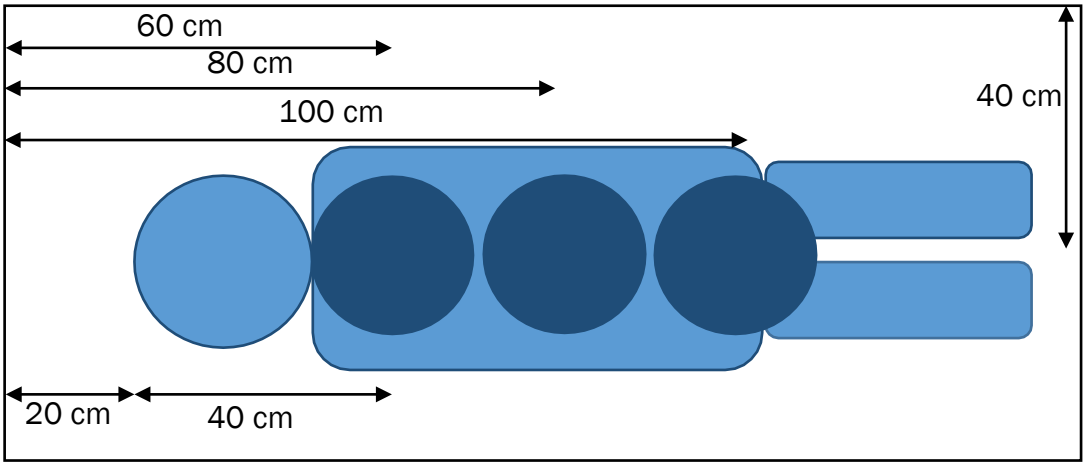


Figure 2 – Location of the three weights

[7] *A Preliminary Anthropometry Standard for Australian Army Equipment Evaluation*, DSTO Defence Science and Technology Organisation, Commonwealth of Australia, August 2014

A measurement was taken from a reference point and later calculated to determine the level of deflection of the mattress at these three points. The top surface of the mattress is considered zero.

In total six bed/mattress products of varying designs were tested. These included three conventional support systems and three corrective support systems. (Listed in Table 2 and detailed in Appendix A - Bed Types.

Experimental body mass profiles

For the purpose of this study the torso was broken up into three sections (thorax /shoulders, lumbar /waist and pelvis /hips), and assessed. While the torso is not three individual sections, the weight of each section applies a different level of force to the corresponding point on the mattress.

The human limbs (arms and legs) and the head were not included in the testing method. The additional weight of these segments (and how they are positioning during lying) would have some impact on the results.

The variation between the three points of the torso for each mattress tested are depicted in the graphs below. Ideally the spinal column should be supported in a neutral position while in the set sleeping postures (side or back lying).

The legend is consistent for all the graphs below. All green lines relate to male data, all blue lines relate to female data.

People size was used to determine the (range of) breadth dimensions at the shoulders, waist and hips for the Australian adult population. Thus each category (male and female) will have a range of dimensions for each point (corresponding to shoulder, waist, hip) on the graphs below.

The diagram[8] below shows the body in side lying, and the movement of the lumbar spine when the waist is and is not supported.
The graph below depicts the three points along the torso (shoulder, waist, hip) and the dimension of these referenced to a neutral position of the spinal column (black dotted line) while in side lying. Hence these dimensions form the theoretical curvature required by the support surface to support a neutral position for the spinal column for Australian adults in side lying.

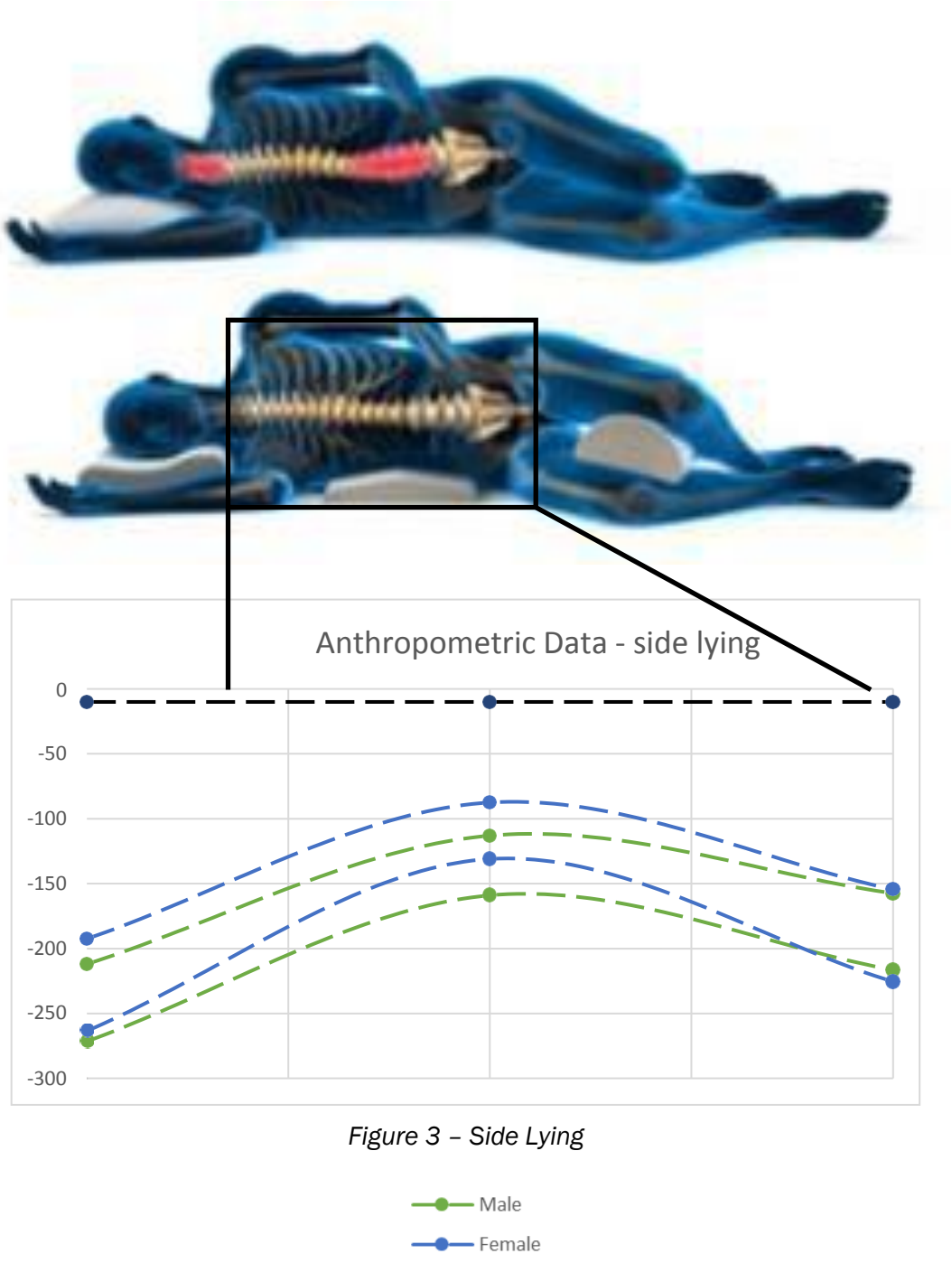


Figure 3 – Side Lying

[8] http://activebackcare.com.au/sleeping-positions-to-relieve-back-and-neck-pain, accessed 10 November 2016

Similarly, according to anthropometric data, the below graph shows the neutral position of the spinal column in supine (back lying) as the range between the two black dotted lines..[8] Hence these dimensions form the theoretical curvature required by the support surface to support a neutral position for the spinal column for Australian adults in supine (back lying).

Note: Figure 4 the black dotted lines show the spinal column curvature, there is not significant difference between males and females.

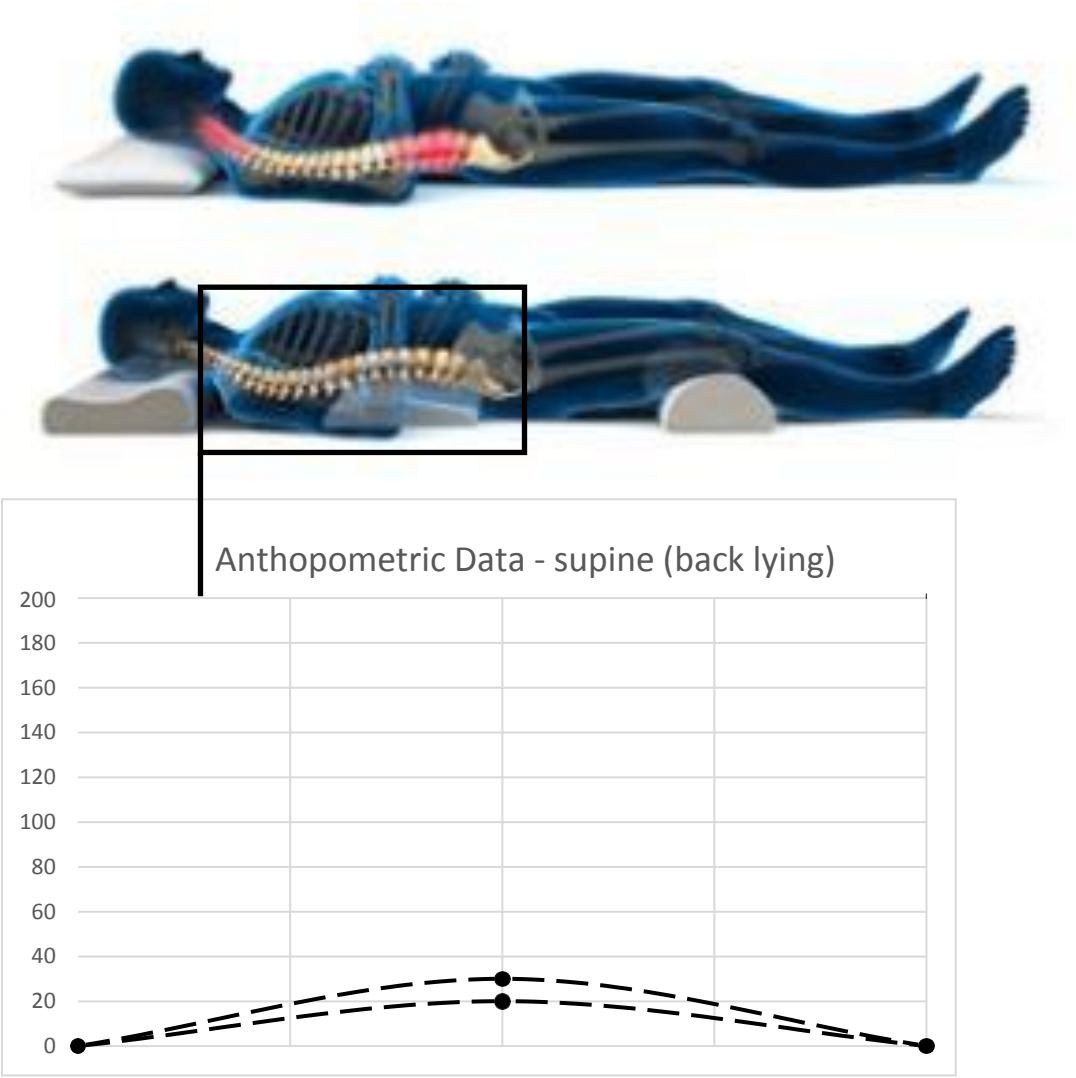


Figure 4 – Back Lying

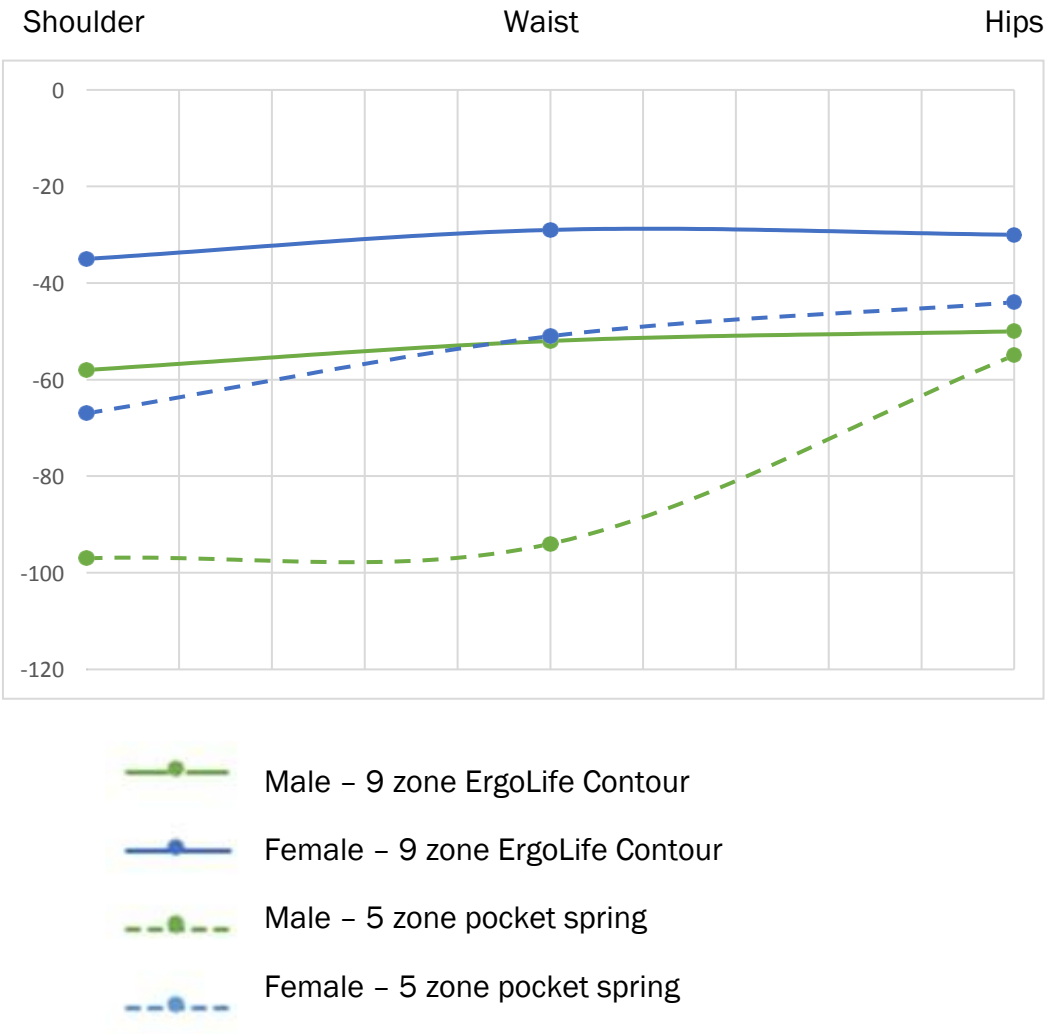
The discussion below relates to how each design matched the contour required for the ranges of loads (in different sections) which were placed upon each bed/mattress product tested.

The products tested have different structural elements (springs, pocket springs foams etc.), within each bed/mattress. These structural elements will be affected by any additional materials applied to the bed's surface or used in its construction, including additional layers (comfort layers, protectors etc.).

The tests were all carried out on mattresses without any additional layers.

5 Zone Pocket Spring vs 9 Zone ErgoLife Contour mattress

The below graph shows a comparison between the 5 Zone Pocket Spring and the 9 Zone ErgoLife Contour mattress.



The 5 zone pocket spring mattress had less deflection at the hips to produce the curves in the graph above. This is likely due to position of the weight at the hips being placed on the next zone of the mattress (a firmer section) thus the interaction between these two regions not allowing for as much deflection as at the shoulders and waist.

Neither the female or male data would provide adequate support in side lying to assist in maintaining a neutral spinal column.

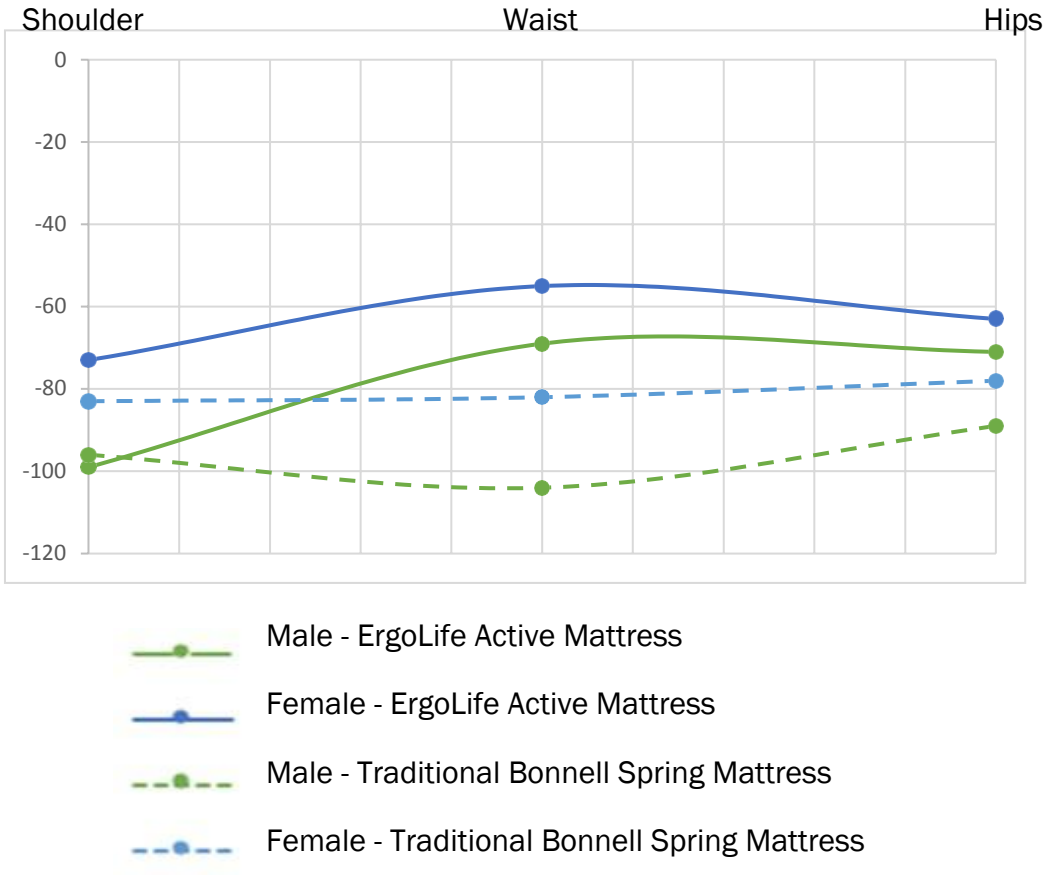
The 9 zone ErgoLife Contour mattress provided a small amount of overall deflection into the mattress, across all three torso segments assessed. This is a firmer mattress than some of the others tested.
The variation in deflection at the shoulders was greater than at the waist and hips. This increased deflection allows for slightly more support at the waist to support the neutral position of the spinal column in both side and back lying.

Note: the lumbar springs in the 9 zone ErgoLife Contour mattress are at 70 cm. The middle of the waist segment was positioned at 80 cm in the test, spaning 20 cm (70 cm – 90 cm). This would have impacted the results, suggesting that adjustability in the lumbar location is still required to increase the support at the waist in lying.

Overall, the 9 zone ErgoLife Contour mattress provided support which was closer to the desired ergonomic shape than the 5 zone pocket spring mattress.

Traditional Bonnell Spring Mattress vs. ErgoLife Active Mattress

The below graph shows a comparison between the results from a traditional bonnell spring mattress and the ErgoLife Active mattress. The ErgoLife Active mattress has a softer foam shoulder zone and an adjustable lumbar support. The lumbar support is created from inserting a section of foam between the springs to act as a stiffener.



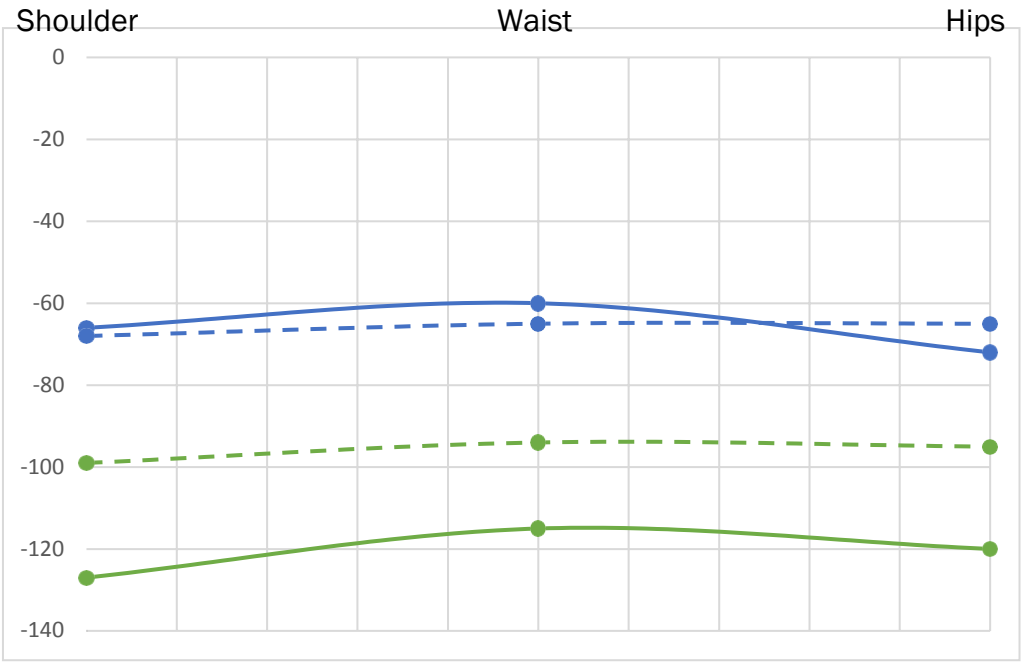
The traditional bonnell spring mattress provides no additional support at the waist to assist in supporting a neutral spine.

The ErgoLife Active mattress showed a greater deflection at the shoulders and hips in comparison to the waist for both male and female. This curve follows the anthropometric data collated for maintaining a neutral position of the spinal column in back lying.

For side lying, ErgoLife Active mattress provides an increase in support at the waist, to allow for a curvature that follows a similar line to that of the theoretical data, whereas the traditional bonnell spring mattress does not

Latex Mattress on an ErgoLife Zero Stress system, with and without adjustment

The below graph shows a comparison between the results from the latex mattress on an ErgoLife Zero Stress system with no adjustment and appropriately adjusted for a 100 kg male and a 50 kg female.



Male – Latex Mattress on an ErgoLife Zero Stress system with appropriate adjustment

Female – Latex Mattress on an ErgoLife Zero Stress system with appropriate adjustment

Male – Latex Mattress on an ErgoLife Zero Stress system with no adjustment

Female – Latex Mattress on an ErgoLife Zero Stress system with no adjustment

The latex mattress on an ErgoLife Zero Stress system with no adjustment showed little variation between each of the points measured. The deflection is slightly greater at the shoulders and hips, allowing for a slight increase in support at the waist.

The latex mattress on an ErgoLife Zero Stress system was appropriately adjusted for the female and male test. This adjustment was determined by an experienced staff member adjusting the mattress for a male and female of similar mass to the test weights.

The latex mattress on an ErgoLife Zero Stress system, appropriately adjusted, allowed the most deflection between the waist and hips of all the bed/mattress products tested. This appears to be as a result of the available adjustment within the ErgoLife Zero Stress system. Additional lumbar support can be adjusted and customised along the length of the mattress. The firmer adjustment mechanism in the bed allows for the support to be tailored to the individual and to achieve a variation in deflection similar to that required to keep the neutral position of the spinal column.

Anthropometry

From the range of anthropometric data collated, the dimensional variations within the torso across the Australia adult population[1] are:

- top of head to armpit - 4cm;
- top of head to waist - 23cm; and
- top of head to hip - 12cm.

The surface area of the weights used to simulate each segment during the testing of the mattresses had a diameter of 20 cm. The torso dimensions differ less than the determined test surface area of each torso segment. As such, the variation in torso length across the Australian adult population could not be assessed against all bed/mattress products. The adjustability observed with both the ErgoLife Active mattress and the latex mattress on an ErgoLife Zero Stress system, appropriately adjusted, would assist with adjusting the position of the lumbar curve and waist for short and tall Australian adults.

The main variation observed in the anthropometric data relevant to this assessment was body mass.

The human torso (shoulders, waist and hips) accounts for about fifty percent of the total body mass. Hence the variation in the force of the torso body segments being applied to the support surface can vary greatly, supporting the conclusion that body mass should be considered when selecting a support surface for individuals. Bed/mattress products need to provide adjustability for the weight of the person. Further, this adjustability would be required on each side of the bed for partners who vary significantly in body mass.

Use of the product

The useability of the adjustable bed designs was relatively easy and readily accessible. They allowed for significant adjustment and for users to be able to change and customise the support setup. “Comfort” is a subjective assessment for each individual and adjustment allows important variability in each side of a bed to achieve as close to a neutral positon of the spinal column in lying as possible. Allowing each person to set up their side of the bed for their own weight, positioning and “comfort” is considered very important, as no bed/mattress products tested can accommodate the variation in anthropometry without any adjustment.

Adjustability is a critical feature, however it is important that users are taught about the adjustment and that user training is provided. This should cover appropriate techniques to ensure that the adjustable aspects of a bed/mattress system and the positioning of the individual within the mattress dimensions are appropriately set up. The bed/mattress system, once adjusted, should provide the required support for the individual and their sleeping postures.

Additionally, the adjustment available in some of the products discussed here may increase the life of the bed/mattress system. As the latex or springs within a mattress compress and deform over time (as would be expected), the adjustability can be used to extend the mattresses life.

Further, it should be noted that there can be a large influence on the nature of the load/deflection characteristics by the addition of surface covers, toppers and comforters.

Conclusions

Body-size data on side lying shows a level of variation that is likely to make that posture uncomfortable for a proportion of users, and so would affect sleep for many.

Most of the bed/mattress products assessed provided some level of variation, to a greater or lesser extent, that matched the anthropometric curve, supporting the waist or lumbar contour however the adjustable bed/mattress products were closer to the desired ergonomic criteria.

Importantly, the ErgoLife Zero Stress system allowed for adjustment, so the desirable support level can be customised very specifically for a given individual.

The conventional bed/mattress products assessed match the desired ergonomic criteria to a lesser extent or not at all. By comparison to the adjustable bed/mattress systems, these products are likely to provide minimal support to the spinal column to achieve a neutral position.

This study also highlights that partner variations should be taken into consideration in mattress design. It can be seen from all the graphs above that the 100 kg male deflected the bed/mattress more so than the female. Independent adjustability for each person (partner) is the only way that the aims of a compliant load bearing bed/mattress for each person can be achieved.

Based on this assessment, the ergonomic principles of a neutral position of the spinal column, thus reducing the strain, can only be achieved through a bed/mattress system which can be adjusted to accommodate the variation of weight as well as the shoulder, waist and hip dimensions of each individual.

[END]

Appendix A - Bed Types

Conventional Product	ErgoLife Product
5 Zone Pocket Spring	9 Zone ErgoLife Contour
Traditional Bonnell Spring Mattress	ErgoLife Active Mattress
Latex Mattress on an ErgoLife Zero Stress System with no adjustments	Latex Mattress on an ErgoLife Zero Stress System appropriately adjusted

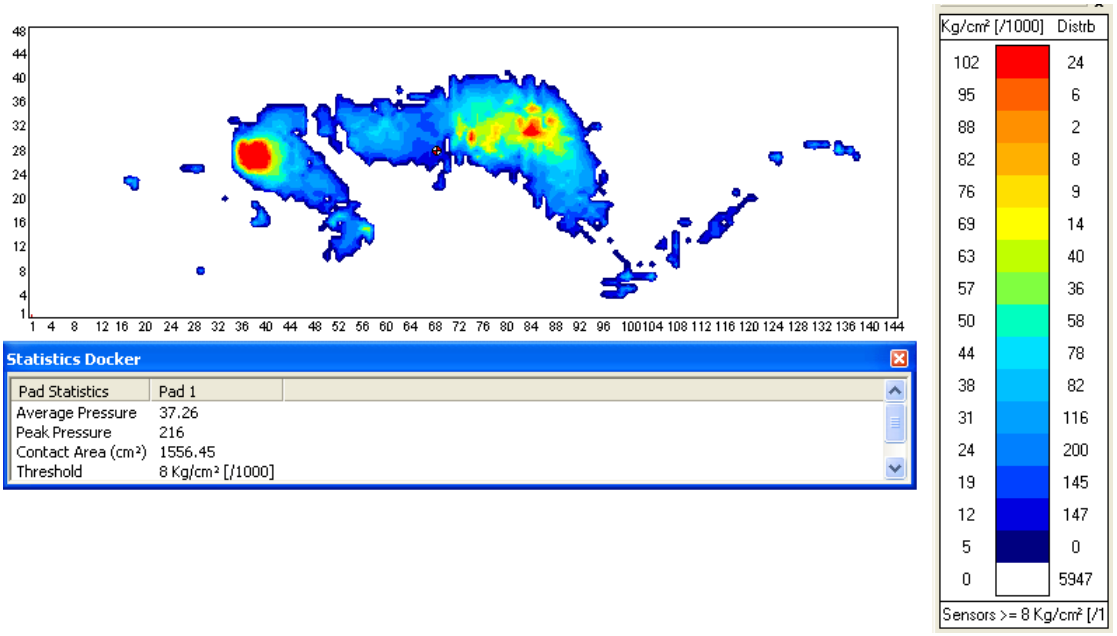
See detailed descriptions below.

Conventional Product	ErgoLife Product
5 Zone Pocket Spring  A 5 Zone Pocket Spring with general zoning, on a standard platform base. A Five zone mattress has a zone in the middle section of the mattress at the waist region. Either side of this zone is the shoulder and hips/upper thigh zones. The top and bottom of the mattress are the head and feet zones. This system allows the mattress to be turned on the bed.	9 Zone ErgoLife Contour Designed with specific lumbar zoning and extra soft shoulder zone, on a standard platform base.
Traditional Bonnell Spring Mattress A coil spring mattress with constant and continuous coil spring construction on a standard platform base.	ErgoLife Active Mattress  A coil spring mattress with a special soft density foam insert in the shoulder area and moveable inserts that provide specific and adjustable lumbar support by inserting foam ‘stiffeners’ between the springs specifically in the lumbar zone. The lumbar support can be adjusted on each side of the bed to suit the individual.

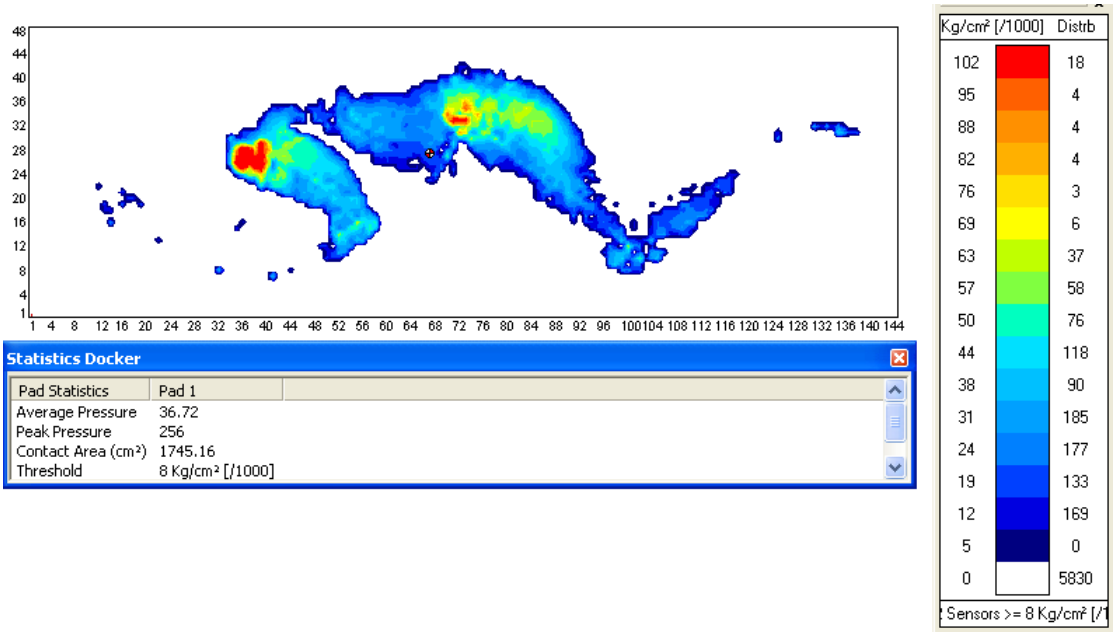
Latex Mattress on an ErgoLife Zero Stress System with no adjustments This mattress is of uniform latex material construction. It was tested on a Ergo Ultra-Fit base system with no adjustments or the base was adjusted to be consistent. This adjustment is the same as a conventional timber-slatted base.	Latex Mattress on an ErgoLife Zero Stress System appropriately adjusted  The base system is adjusted via external dials to lower and raise the slats. The slats supporting the mattress in the shoulder and hip areas are lowered and lifted in the lumbar area. This provides additional support at the waist, which in turn provides additional support to the spine.

Appendix B – Noel Lythgo pressure mapping

Latex Mattress, Platform base, female



Latex Mattress, Variable support base, female.



Appendix C – Results

The calculated deflection of the mattress surface at the three measured locations along the spinal column (shoulder, waist and hip) are shown below:

Bed Deflection (mm)	100 kg Male			50 kg Female		
	shoulder	waist	hip	shoulder	waist	hip
Latex Mattress on an ErgoLife Zero Stress System with no adjustments	-99	-94	-95	-68	-65	-65
Latex Mattress on an ErgoLife Zero Stress System appropriately adjusted	-127	-115	-120	-66	-60	-72
5 Zone Pocket Spring	-97	-94	-55	-67	-51	-44
9 Zone ErgoLife Contour	-58	-52	-50	-35	-29	-30
Traditional Bonnell Spring Mattress	-96	-104	-89	-83	-82	-78
ErgoLife Active Mattress	-99	-69	-71	-73	-55	-63
Traditional Bonnell Spring Mattress with 40 mm topper[9]	-97	-95	-90	-79	-67	-68
ErgoLife Active Mattress with 40 mm topper[9]	-83	-73	-75	-61	-57	-60

[9] These tests are not discussed in this report.