The effects of surface gradient on the human spine

The Effects of Surface Gradient on the Human Spine

by

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Abstract

The purpose of this thesis is to investigate the effect of surface gradient and heeled footwear on standing posture. Daily activities are not always performed on horizontal ground and understanding how posture alters in different scenarios is vital in order to know how a specific task is going to affect a person. Under normal conditions a person's standing posture is muscularly efficient; deviation from a normal posture reduces the body's efficiency and increases the rate of muscle fatigue often resulting in discomfort and pain. Increasing postural lean and reducing the amount of curvature are both risk factors for back pain and back injury, both leading causes for visits to the doctor and lost work hours. In order to gain this understanding, experiments have been designed and conducted which measure the spinal contour from the T1 vertebra to L5 vertebra of 39 subjects standing barefoot and in two different pairs of heeled shoes on 13 different surface gradients from 30° downhill up to 30° uphill. The spinal curvatures are measured using a commercially available device giving over 2000 spinal contours for analysis. New software is developed which takes the raw data from the commercial device and allows different techniques to be used to analyse the spinal contours. The software developed in this study calculates the thoracic and lumbar curvature angles using two complimentary methods, with two different vertebral ranges as well as calculating the thoracolumbar lean and the sacrum angle. The effect on each of these spinal parameters is analysed individually before looking at how the spine as a whole adapts to different surface gradients and different footwear. Results are analysed by gender in order for gender differences to be observed. The effects of surface gradient, heeled shoes and the combination of heeled shoes on surface gradients on posture are all reported.

Key words: Posture, Surface Gradient, High Heels, Thoracolumbar, Postural Lean, Spine Curvature.

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Table of Contents

List of Tables

Table of Figures

Chapter 1 - Introduction

This thesis describes an investigation into the changes in posture which occur when people are standing on surfaces of different gradients and when wearing heeled shoes. Changes in posture can increase the risk of back injury and developing back pain.

Understanding posture and how it alters in different scenarios is vital in order to know how a specific task is going to affect a person's posture. This knowledge enables counter-measures and tools to be designed and guidelines to be written to assist in keeping spinal parameters within normal/safe ranges. A person's normal posture is in most cases an efficient posture; deviating from a normal posture reduces the body's efficiency and increases the rate of muscle fatigue. In order to gain this understanding, experiments needed to be conducted and the results analysed.

Posture refers to how the body is aligned. The spine is never straight and the curves it adopts are the main factor on the posture that a person has. For most people a normal posture requires the spine to have 3 distinct sagittal curves; the cervical curve, the thoracic curve and the lumbar curve. Although the sacrum is also curved, because it fuses with the pelvis its curvature does not change based on the person's actions. The thoracic curve is a kyphotic curve, that is, a convex/outward curve. The lumbar curve is lordotic, and has a concave or inward curve. Posture is defined not solely by the curvatures that the spine adopts. It also includes the position of the head, limbs and pelvis. Good posture is generally understood to be when the body is in equilibrium, the muscles are not strained and therefore the body is in its most efficient state. Viewed in the sagittal plane, a good standing posture is defined as when a plumb line would fall through the tragus of the ear, the greater trochanter (the upper eminence of the femur) and the talocrural joint (ankle joint). Although the spine has three distinct sagittal curves, the spine is one structure and as such a change in one curvature can have repercussions in the others [1]. The curvatures having the largest ranges are the thoracic and the lumbar curves, together referred to as the thoracolumbar spine. Laterally, the spine should be almost straight from top to bottom (there is often a slight curve to the dominant side [2]) and the shoulders level.

Everyone has a different method for maintaining balance when standing upright [3]. Whenever a person's spinal curvatures change, in order for them to maintain their balance, the effort required of the muscles changes. It is valuable to know what these compensatory changes in posture are and how significant they are. Activities and environments which cause changes in the thoracolumbar spine resulting in a poor posture are risk factors for low back pain or back injury [4]. Poor posture itself has many etiologies, congenital (present at birth), something developed over time; such as scoliosis, kyphosis or lordosis, short term pathology, idiopathic or environmental. To understand why the human body assumes certain postures and in what situations/environments they are adopted can provide information such as what tasks or environments should be modified or avoided, or where exposure should be limited.

The way in which individuals maintain balance can affect muscle activity, prolonged and inefficient muscle activity can result in accelerated fatigue and can lead to pain in those muscles [5]. As daily activities are not always performed on horizontal ground, an understanding of the effect that sloped ground has on posture is crucial in understanding how the body maintains stability. Adopting a bad posture for an extended period of time may cause back pain as the muscles are subjected to increased activity which causes fatigue. Understanding when the human body assumes a bad posture could reduce the amount of back pain that is experienced by many people. This thesis details experiments which look into the postural changes that the spine undergoes in order to maintain balance in environments where the surface that the person is standing on is not horizontal or when the person is wearing heeled footwear.

Back pain in the UK has been shown to affect 49% of adults at least once each year [6] and that 80% of people will experience back pain for at least 24 hours at least once in their lives [7, 8]. In the US it is one of the most common reasons for lost work hours and visits to the doctor [9, 10]. Given that 95% of back pain in the UK is acute back pain [11], that is, back pain that is only temporary and is due mainly to the way that the bones, ligaments and muscles of the back are working together, it is a very serious problem. Educating people as well as patients in avoiding situations and environments which may injure their backs may help to reduce this figure.

This research aims to quantify the postural changes due to the environments that the subject is placed in and to provide and analyse thoracolumbar data for male and female postures using skin surface devices. This will be achieved by investigating appropriate spinal measurement techniques, conducting an experiment to measure the spines of subjects and developing software to process the raw data so that analysis can be carried out.

This thesis is broken down as follows:

Chapter 2 provides a background to the spine column, the vertebrae, intervertebral discs, spinal curvatures, posture, postural problems, spinal disorders and causes of back pain and a review of the work that has been conducted in this field.

Chapters 3 and 4 gather and summarize current methods of posture measurements and analysis, focusing on when and where these methods are applicable, their advantages and their limitations. These chapters conclude with the reasons for the choice of measurement device and analysis techniques for measuring the subjects of the experiment and the subsequent analysis of the results.

Chapter 5 describes the experiments, the subjects chosen, the methodology and the development of software for the processing of measurements into analyzable data. The experiments were conducted using 39 asymptomatic subjects, 20 males and 19 females. Each subject had their T1-L5 sagittal spinal contour measured using a skin surface device on 13 different surface inclinations in the range of -30° to 30° while barefoot and the female subjects repeated this wearing two different pairs of heeled shoes. New software was developed as part of this research to improve on the software provided with the spinal measurement device to allow different analyses of the data to be carried out.

Chapter 6 observes the effect of heeled shoes and non-horizontal surfaces on the T1-L5 inclination of the spine (thoracolumbar offset) and also compares male and female thoracolumbar offsets.

Chapter 7 focuses on the effects of heeled shoes and different surface gradients on the thoracic and lumbar curvatures of the spine. Two techniques and two different measurement ranges are used for each curvature. Comparisons are made between the male and female curvature differences.

Chapter 8 examines the effect on the sacrum (hip) angle of heeled footwear and different surface gradients. The sacrum angle is one of the major factors influencing the thoracolumbar offset [3]. Comparisons between how males and females alter their sacrum angles is also investigated.

Chapter 9 summarizes the findings of this research and its contribution to the knowledge base.

A Glossary is included before the Appendices. Appendix 1 shows the spinal parameters calculated during this research for each subject on each surface and wearing each pair of shoes. Appendix 2 shows the software design documentation.

Chapter 2 - Literature Review

This chapter provides the background information on the spine, its components, structure, curvatures, the problems and disorders that can affect it and the research that has investigated its properties and functions.

2.1 The Human Spine

The adult vertebral column is generally made up of 24 individual vertebrae with a further five vertebrae which become fused to form the sacrum and then between three and five small vertebrae that fuse to form the coccyx (see Figure 2-1).

The 24 vertebrae are split up into three sections. The cervical spine refers to the seven vertebrae that make up the neck. The thoracic spine refers to the 12 vertebrae that make up the upper back which are the vertebrae that the ribs connect to, and the lumbar spine which consists of five vertebrae which make up the lower back. The changes in the vertebrae between the spinal sections are gradual.

The roles of the vertebral column in the human body are many; it provides protection for the spinal cord and with the ribs it protects the organs in the thoracic cavity. The vertebrae provide connection points for the muscles, ligaments and tendons; with these tissues it allows movements in all planes as well as axial rotation and allows the body to maintain balance. Through the curvatures and the vertebral bodies it distributes weight down to the pelvis and legs.

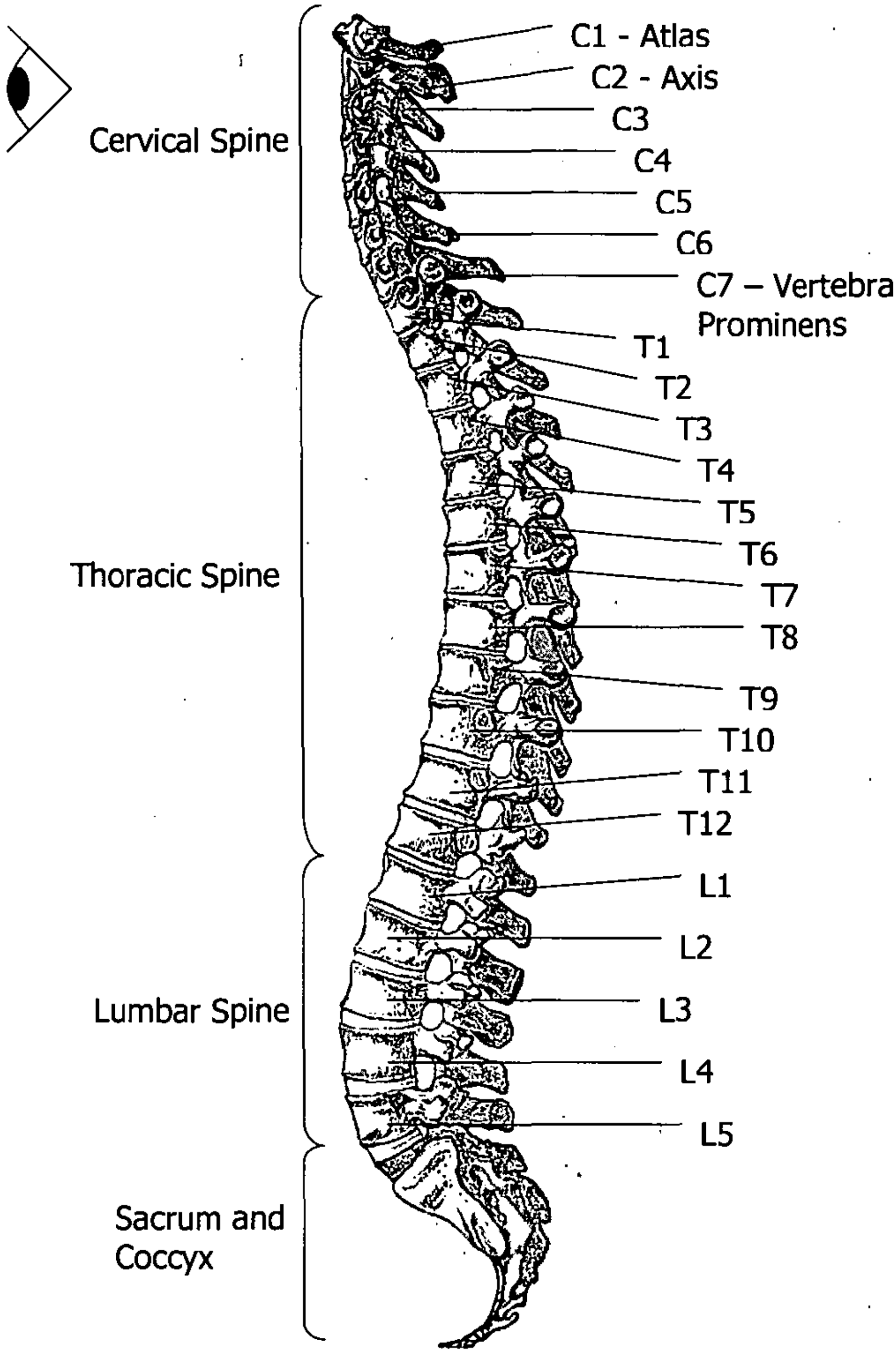

Figure 2-1 - The Human Spine[1]

[1] Adapted from Gray's Anatomy [2]

Gray's Anatomy [2] states that the average male vertebral column is 71cm in length, it is thought that this figure refers to the plumb length. It also states that the break-down of section lengths is 12.5cm, 28cm, 18cm and 12.5cm for cervical, thoracic, lumbar and sacrum plus coccyx respectively. For females the breakdown is not given, only the total length which is given at 61cm. Using the same ratios as the male breakdown would put the average female sections at 10.7cm, 24.1cm, 15.5cm and 10.7cm for cervical, thoracic, lumbar and sacrum plus coccyx respectively. It is unknown who the sample population for these figures were.

Most vertebrae have a vertebral body; this part of each vertebra is the load bearing part and is located to the anterior of the vertebra. Vertebral bodies are roughly cylindrical. The superior and inferior surfaces of the vertebral bodies are known as the endplates. Most of the vertebrae also have three processes – bony prominences which the ligaments and muscles connect to – a spinous process at the posterior of the vertebra and a transverse process on each side of the vertebra. Between the vertebral body and the transverse processes are the pedicles and between the transverse processes and the spinous process are the laminae. The pedicles and laminae form the vertebral foramen – a hole in the vertebra for the spinal cord to pass through and offer a certain amount of protection to it (see Figure 2-2).

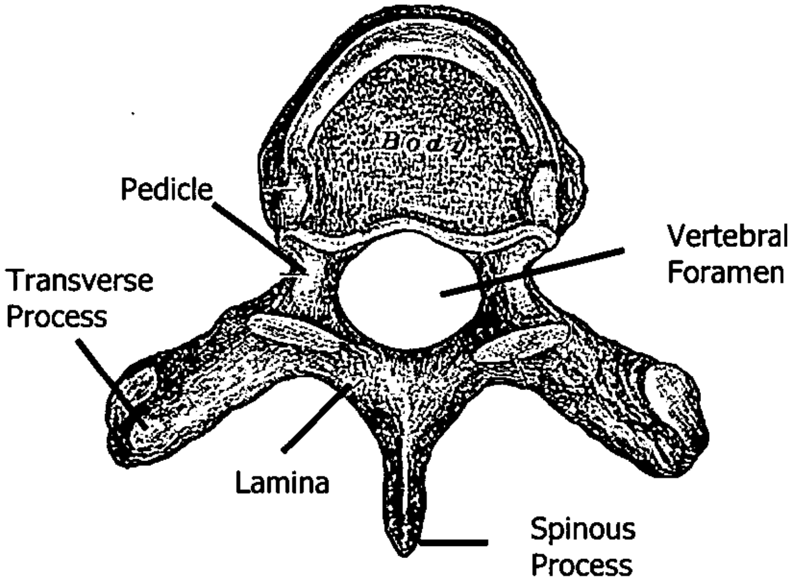

Figure 2-2 - Typical Vertebra[1]

Each vertebra is connected to its adjacent vertebrae at three points. The main articulation point is the intervertebral disc which is located between adjacent vertebral bodies (see Figure 2-3). Each vertebra then has two superior articular facets for articulating it with the adjacent superior vertebra and two inferior articular facets and for articulating it with the adjacent inferior vertebra.

[1] Adapted from Gray's Anatomy [2]

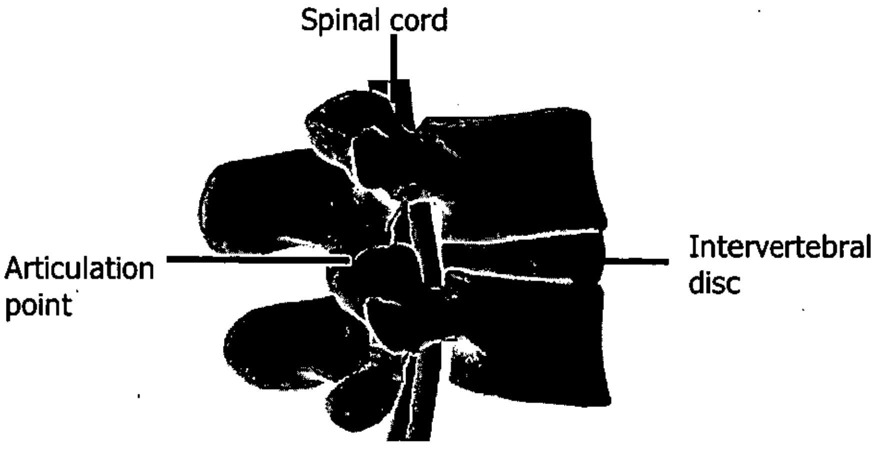

Figure 2-3 – Vertebral Articulation Points[1]

Each of the vertebrae is referred to as the section of the spine they are in followed by the position in the curve. For example T4 refers to the 4th vertebra from the top of the thoracic section of the spine. C refers to the cervical section; L refers to the lumbar section and S to the sacrum. Generally, there are not references for the coccyx. C0 refers to the occipital bone which is a bone of the posterior inferior skull to which the spinal column connects.

Each of the sections of the spine has a particular curve. The thoracic spine and the sacrum have an anteriorly concave curve which is known as a kyphotic curve. The lumbar spine has a curve which is anteriorly convex and known as a lordotic curve. The cervical spine usually has a lordotic curve, however it is not uncommon for it to be straight, kyphotic or 'S' shaped [12].

2.1.1 Cervical Spine

The cervical vertebrae are the smallest of the vertebrae. The transverse foramen (an opening) passes through the transverse process of each of the cervical vertebrae. The transverse foramen gives protection to the vertebral arteries and veins which go to the brain. Cervical vertebrae

[1] Adapted from image at http://www.wkni.org/

have very small vertebral bodies due to their being less weight bearing but very large vertebral foramen as this is where the spinal cord is largest. There are three special cervical vertebrae. C1 is known as the atlas, it has no body. C2 is also known as the axis. The axis articulates with the atlas so that the head can turn left and right. Vertebra Prominens, the C7 vertebra is the final cervical vertebra and resembles a thoracic vertebra more than a cervical vertebra. However, it does not have any facets for rib articulation. The spinous process of this particular vertebra can be felt at the surface at the base of the neck.

2.1.2 Thoracic Spine

The thoracic vertebrae are larger than the cervical vertebrae. They have larger bodies but smaller vertebral foramen and the processes are longer and thinner, although the processes of T10-T12 start to resemble lumbar vertebral processes. The thoracic spine supports the weight of the head, neck and the organs within the rib cage and they have articulation facets for the ribs. T1 has a facet on each side for articulation with the first rib pair as well as an inferior demifacet on each side for articulation with the second rib pair. T2 has a superior demifacet on each side which with the inferior demifacets of T1 allow articulation with the second rib pair. T2 also has an inferior demifacet on each side which with the superior demifacets of T3 allows articulation with the third rib (see Figure 2-4). In the same way, T3-T8 all have superior and inferior demifacets on each side and T9 has just a superior demifacet on each side for articulations with the second to ninth ribs. T10-T12 have whole facets on each side for articulation with the tenth to twelfth ribs. T1-T10 also have whole facets on each transverse process as another articulation point with the ribs. T11 and T12 do not have any facets on the transverse processes, allowing more freedom of movement for the eleventh and twelfth ribs, known as the floating ribs, which also do not connect to the sternum at the front of the rib cage.

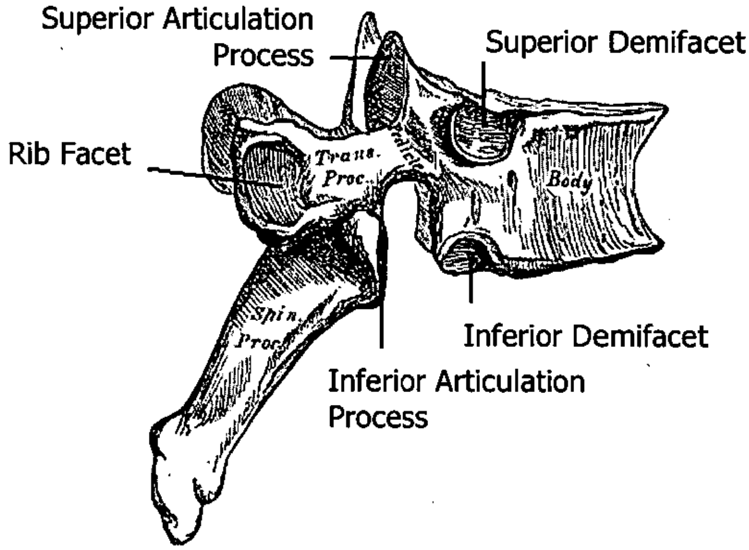

Figure 2-4 - Typical Thoracic Vertebra[1]

2.1.3 Lumbar Spine

The lumbar vertebrae are the largest of the vertebrae. They have the largest bodies and the vertebral foramen are not as small as the thoracic vertebral foramen. The processes are shorter but larger as the lumbar vertebrae have to support the weight of the head, neck, thorax and abdomen (see Figure 2-5). The processes are large to give a larger surface area for the connecting ligaments/muscles.

[1] Adapted from Gray's Anatomy [2]

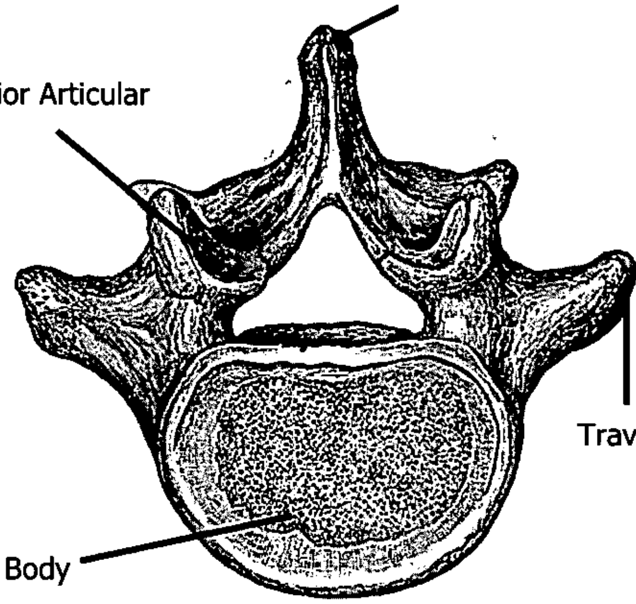

Figure 2-5 - Typical Lumbar Vertebra[1]

2.1.4 Sacrum

The five fused vertebrae that make up the sacrum connect superiorly to the final lumbar vertebra laterally to the iliac crests of the pelvic bone and inferiorly to the coccyx. The sacrum transfers the weight of the upper body to the pelvic girdle; it also provides protection for the reproductive, digestive and excretory organs. Fusion of the sacral vertebrae starts in late adolescence and is usually completed in the mid-twenties. The female sacrum is shorter, wider and less curved than the male sacrum [2]. The female sacrum is also directed more obliquely backward, to increase the size of the pelvic cavity [2, 3]. The male sacral curvature is more evenly distributed over the whole length of the fused vertebrae [2].

2.1.5 Coccyx

The coccyx is made up of 3-5 vertebrae that have started to fuse by the time a person is 26. Complete fusion is not reached until late adulthood [2].

[1] Adapted from Gray's Anatomy [2]

2.1.6 Intervertebral Discs

Between each vertebral body there is an intervertebral disc. The intervertebral discs are compressible, allowing the vertebrae to compress and uncompress them when the spine flexes or extends. The discs account for roughly ¼ of the length from C2 to L5. The discs contain water and lose water throughout the day. When a person sleeps or lays supine, the discs are able to recoup the water. With age, the discs lose their ability to retain water which causes the disc to be less pulpous (thus making vertebral fractures more likely) and smaller (causing a loss in the person's height.)

2.2 Curvatures of the Spine and Curve Development

The adult spinal column exhibits four curves when viewed laterally, these are the cervical, thoracic, lumbar and sacral curves. The curvatures approximately correspond to the regions of the spine. The curvatures of the spine change with age. Generally, by the time a person reaches adolescence their spine has all four curves fully developed. However, these curves can change due to weight gain, pregnancy and other factors affecting body mass. The role of the curves is for efficient:

- load absorption
- spinal musculature
- maintenance of the upright posture
- shock absorption

Without the curves of the spine, back-pain can arise as the muscles have to do more work when loaded, working or standing.

The thoracic and pelvic curves are referred to as the primary curves, as they are present during foetal life. The cervical and lumbar curves are secondary, compensatory curves that develop after birth. The cervical curve develops between when a child is able to hold up its head, at around three or four months, and when they are able sit upright, at around nine months [2]. The lumbar curve develops at around 12 to 18 months, when a child starts to walk [2].

From the skull, the first curve, the cervical curve is generally posteriorly concave but studies have found different curvatures in different people [12, 13]. Gray's Anatomy states that a normal cervical curvature starts from C2 and finishes within the T2 vertebra and has the least amount of curvature [2]. In the literature the cervical curvature is quoted as being between 21° and 34° for asymptomatic people with a lordotic cervical curvature [12, 13, 14, 15]. These studies did find people that were asymptomatic with non-lordotic cervical curvatures however the results from these subjects were not incorporated.

The second curve is the thoracic curve and is posteriorly convex. According to Gray's Anatomy, it starts from the end of the cervical curve and finishes within the T12 vertebra [2]. However, other studies such as those done by Vialle *et al* [3] and Stagnara *et al* [16] have found that the thoracic curvature can extend up to L2 for a significant number of people. This is conceivable as the L1 and L2 vertebrae contribute the least to the curvature of the lumbar spine [2, 3]. The most posterior point of the thoracic curve is the spinous process of T7 [2]. The thoracic spine's range of motion is limited, mainly due to the many rib/vertebrae connections and the long spinous processes [17]. Studies of the thoracic spine found the curvature to be between 23° and 45° for asymptomatic people [3, 16, 18, 19, 20, 21]. Female thoracic curvature is generally found to be less than male thoracic curvature however not all studies find the differences to be significant [3, 20].

The lumbar curve is the third curve of the spine and starts from the end of the thoracic curve and ends between the L5 vertebra and the sacrovertebral articulation [2]. The lumbar curve is posteriorly concave. The male lumbar curve is flatter than the female lumbar curve. The curvature is greatest amongst the L3-L5 vertebrae [2, 3]. Studies of the lumbar spine found the curvature to be between 25.6° and 60.2° for asymptomatic people [3, 16, 19, 20, 21, 22]. Male lumbar curvature is generally found to be less than female lumbar curvature [3, 20].

The final curve is the pelvic or sacral curve. This begins between the L5 and S1 vertebrae at the sacrovertebral articulation, and ends at the caudal end of the coccyx [2]. The sacral curve is a posteriorly convex curve directed downward. A person's sacral curvature does not change, as the vertebrae are fused, however the orientation of the sacrum can change and a change in orientation causes changes to the lumbar curve.

2.3 Spinal Studies Review

Measurement of the spine is important for a number of reasons; modelling the spine and anticipating or knowing how it reacts to certain situations and environments is essential for peoples' health and safety. Knowing what defines normal spinal parameters and their normal variations can assist in diagnosing pain, discomfort and disability in subjects with values outside of the normal ranges. In order to correct spinal problems, surgeons, therapists and carers need to know what the normal ranges for spinal parameters are. Normal ranges need to be known in order to know whether correction/therapy has been successful. The spine adapts differently to each environment and each task it is subjected to, the results of the adaptations can be detrimental to the person. In controlled tests, observing whether any spinal parameters fall outside normal ranges can enable guidelines to be written informing people of the potential dangers of certain activities. Knowing how the spine adapts to a specific task can enable counter-measures and tools to be designed which keep spinal parameters within normal/safe ranges.

As humans get older their bodies change; sometimes, changes do not occur normally and people develop deformities. Knowledge of the normal ranges of spinal parameters can help screen for and detect developing deformities before they become serious and possibly life threatening.

There are many different spinal parameters to measure and with the added complexities of age and gender, environment and activities there is much to investigate. The following section details some of the work conducted in investigating the normal values of various spinal and musculoskeletal parameters for subjects either at ease or performing an activity such as lifting or walking. A number of them focus on how age and gender can affect the results. The techniques used in measuring subjects vary greatly and will be investigated further in the following chapters. As new technologies emerge, which can measure with more accuracy or measure the currently impossible, more information will become available.

2.3.1 Static Spinal Measurement

The curvatures of the spine are very important to the human body; they allow for efficient use of the muscles and load distribution as well as for absorbing shock. The amount of curvature in each section of the spine is also important; too much as well as too little curvature in any region of the spine can reduce effectiveness and cause pain.

Cervical Spine

The cervical spine vertebrae are the smallest vertebrae, they have little weight bearing capacity but need to support the weight of the head and prevent it from falling forward or backward. As mentioned, the cervical spine usually has a lordotic curvature. Without the lordotic curvature or with weak cervical spine muscles the cervical spine cannot function correctly. Harrison *et al* [12] investigated alternative cervical vertebral arrangements and whether non-lordotic curves could predict neck pain. From the sample of 400 subjects, numerous alternative curves were found: straight curves, kyphotic curves, kypho-lordotic and lordo-kyphotic curves and mid-cervical kyphotic curves. For the 252 subjects that were free from cervicocranial symptoms, the C2-C7 lordotic curvature, using absolute relative angle (ARA), was 34° (9.39°). The C2-C7 ARA is the angular difference between the line subtended from the posterior body of C2 and the line subtended from the posterior body of C7. They determined that there was no significant difference between the cervical curvature between the male and female subjects.

In a review of studies by Seaman and Troyanovich [14] it is stated that Gore *et al* found the ARA of 200 asymptomatic subjects to be 21°. A study by McAviney *et al* [13] found the average ARA of 96 asymptomatic subjects with lordotic cervical spinal curves to be 25°. McAviney *et al* also identified subjects with non-lordotic curvatures which were excluded from the results. Those subjects with reduced curvature and those with non-lordotic curvature in all of these studies generally had neck problems. McAviney *et al* [13] and Harrison *et al* [12] also state that the Gore *et al* average for asymptomatic subjects with only lordotic curvatures was 23°.

Dvir and Prushanski [23] investigated the normal cervical range of motion (the difference between a fully flexed cervical spine and a fully extended cervical spine) in 25 subjects, using an ultra sound system mounted to the head. The results are outlined in Table 2-1.

Table 2-1 - Results of Dvir and Prushanski [23]

	First Measurement Mean (SD)	**Second Measurement Mean (SD)**
Extension	62.4° (18.8°)	58.5° (18.2°)
Flexion	59.9° (13.0°)	57.7° (13.0°)

Harrison *et al* [15] X-rayed the cervical spines of 72 asymptomatic subjects, 52 acute neck pain subjects and 70 chronic neck pain subjects. They analysed the data using three methods. They tried to find the set of ellipse arcs which would pass within 1mm of the superior posterior and inferior posterior points of each of the vertebral bodies between C2 and T1. The result of the elliptical modelling found that the arc of a circle will pass within 1mm of all the points. They also measured the ARA and the Cobb angle (see Section 4.1) of the cervical spine. Table 2-2 shows the average ARA and Cobb angles for each of the three groups.

Table 2-2 - Results of Harrison *et al* [15]

	Asymptomatic Mean (SD)	Acute Pain Mean (SD)	Chronic Pain Mean (SD)
ARA C2-C7	34.5° (9.82°)	28.6° (10.64°)	22.0° (14.59°)
Cobb C2-C7	26.8° (9.72°)	16.5° (8.74°)	12.7° (12.54°)
Cobb C1-C7	55.1° (10.42°)	47.6° (9.26°)	45.9° (15.16°)

The differences between the three groups are all significant ($p < 0.001$). In conclusion, these results show that people with less curvature in their necks are going to experience pain, the onset of which depends on the amount of curvature, i.e. less curvature signifies longer lasting pain.

Thoracic Spine

The thoracic vertebrae are larger than the cervical vertebrae as they have to bear more weight. The amount that each thoracic vertebra can move relative to their adjacent vertebra is reduced due in part to the ribs. Problems in the thoracic spine can reduce mobility, cause pain and be debilitating as well as potentially causing death. The thoracic spine and the ribs control the volume of the thorax which contains the heart and lungs. Too much curvature can reduce this volume and cause breathing difficulties. Many investigations into the thoracic spine have been conducted. Work by D'Osualdo *et al* [24], Goh *et al* [25], Harrison *et al* [18], Harrison *et al* [26], Hinman [27] and Kado *et al* [28, 29] have looked at measuring the curvature of the thoracic spine in both asymptomatic and symptomatic subjects.

D'Osualdo *et al* [24] measured the maximum angle of thoracic kyphosis in 145 young adult subjects suffering from kyphosis (excessive curvature of the thoracic spine, see Section 2.4.1) and or scoliosis (lateral curvature of the spine, see Section 2.4.3). D'Osualdo *et al* used X-rays and a device called the arcometer (see Section 3.6) for measuring the thoracic curvature. The curvature was calculated using the chord and the rise of the curve (see Section 4.4). The results of the study are outlined in Table 2-3.

Table 2-3 - Results of D'Osualdo *et al* [24]

	Group 1	Group 2	Group 3
Max. Kyphosis (Arcometer) Mean (SD)	39° (18°)	39° (13°)	37° (12°)
Kyphosis Range (Arcometer)	7 – 95°	3 – 76°	18 – 68°
Max. Kyphosis (X-ray) Mean (SD)	42° (17°)	41° (14°)	37° (10°)
Kyphosis Range (X-ray)	4 – 95°	4 – 84°	21 – 59°

D'Osualdo *et al* determined that there were significant disagreements between the two measurement techniques but that the arcometer showed low inter/intra-observer differences. The results from this study show how large the range of kyphosis can be in symptomatic subjects. It should be noted that these subjects were young adults and therefore had not reached skeletal maturity and that some of them were suffering from scoliosis as well as kyphosis.

Hinman [27] compared the thoracic curvatures of younger and older asymptomatic women using flexicurve tracings. She found that older women have significantly more thoracic curvature both when standing in a relaxed posture ($p < 0.018$) and in an erect posture ($p < 0.001$) and that the thoracic spine in older women was significantly stiffer than in younger women ($p < 0.001$). Stiffer spines were determined to be those which had a smaller difference between relaxed and erect postures.

Kado *et al* [28, 29] studied thoracic kyphosis in older subjects. In the study published in 2004 [28], they examined 1353 subjects for hyper-kyphosis (excessive but gradual kyphosis) to determine whether hyper-kyphosis causes higher rates of mortality in older men and women. The measurements were performed with the subjects in the supine position and hyper-kyphosis was defined as requiring one or more blocks being placed under the head in order to achieve a neutral head position (see Section 3.9). The results of the study concluded that hyper-kyphosis did cause higher rates of mortality in older people due to atherosclerosis. Their study published in 2005 [29] used the same method of determining hyper-kyphosis. The study used 1578 subjects over 55 years old from a community to determine whether hyper-kyphosis has an effect on physical function. They established that 21% of the females and 44% of the males had hyper-kyphosis and that hyper-kyphosis does cause physical functional difficulties.

Harrison *et al* [18] and Harrison *et al* [26] looked at modelling the curvature of the thoracic spine of the arc of an ellipse/circle (see Section 4.7). Harrison *et al* [18] radiographed 80 asymptomatic subjects to determine the Cobb angle and whether the thoracic curve could be modelled on an ellipse. They found that the T2-T11 curvature could be modelled on a 70° ellipse arc with major:minor axes ratio of 0.6 – 0.72 and the major axis parallel to the posterior vertebral body of the T11 vertebra. The results of the Cobb angle analysis are given in Table 2-4.

Table 2-4 - Results of Harrison *et al* [18]

Vertebral Range	**T1-T12**	**T2-T11**	**T3-T10**
Cobb Angle	44.2°	39.9°	33.3°

Harrison *et al* [26] radiographed and modelled the thoracic curvature of 50 asymptomatic subjects. They found that the T1-T12 thoracic spine can be modelled on a 72° ellipse arc with major:minor axes ratio of 0.69 and the major axis parallel to the posterior vertebral body of the T12 vertebra.

Thoracolumbar Spine

The thoracolumbar spine is the part of the spine consisting of the vertebrae between T1 and L5 inclusive. Numerous researchers have studied the thoracolumbar spine as changes in the thoracic spine cause changes in the lumbar spine and vice-versa.

Vialle *et al* [3] X-rayed 300 asymptomatic subjects in the sagittal plane in order to measure a number of thoracic, lumbar and sacral parameters. The results from the study can be seen in Table 2-5. Sagittal offset is the angle between vertical and the line from the selected vertebra to the centre of the bicoxofemoral axis (the imaginary line between the femoral heads). The sacral slope is the angle that the cranial end-plate of the sacrum makes with the horizontal. The results show that the male subjects had more curvature in the thoracic region but less curvature in the lumbar region than the female subjects. This was significant ($p < 0.001$) for the lumbar curvature. The results also show that the male subjects leant further forward than the female subjects for both T1 and T9 offsets; the T1 offset was significantly different ($p < 0.05$). The sacral slope of the female subjects was significantly more than in the male subjects ($p < 0.05$) i.e. the female subjects' sacrums are rotated more anteriorly than the male subjects' sacrums.

Table 2-5 - Results of Vialle *et al* [3]

Parameter	Mean (SD)	Males Mean (SD)	Females Mean (SD)
T4-T12 Cobb	40.60° (10°)	41.7° (10°)	39° (10°)
Max. Thoracic Cobb	41.20° (10°)	42.4° (9.8°)	40° (10°)
L1-L5 Cobb	43° (11.2°)	41.4 (11°)	46.2° (11°)
Max. Lumbar Cobb	60.2° (10.3°)	59.2° (10.12°)	62° (10°)
T1 Sagittal Offset	1.35° (2.7°)	1° (2.7°)	2° (2.7°)
T9 Sagittal Offset	10.35° (3°)	10.2° (3.1°)	10.5° (3°)
Sacral Slope	41.2° (8.4°)	41° (8.5°)	43.2° (8.4°)

For offset values, positive indicates the subjects were leaning forward[1]

Mannion *et al* [19] measured the lumbar and thoracic curvatures, the thoracic, lumbar, sacral and global range of motions (RoM) and the sacral angle of 20 asymptomatic subjects using the SpinalMouse®. The SpinalMouse® is a commercially developed device which records the spinal contour as it is moved along the skin parallel to the spinous processes. The results of the experiment can be seen in Table 2-6. The global inclination is the angle between the vertical and the line between C7 and

[1] The results for the T1 and T9 Sagittal Offsets have been negated for consistency.

the sacrum. The mean T1-T12 curve is close to the results of Vialle *et al* [3], however the T12-S1 curve is very different. This is where differences can be seen between measurements by X-rays/MRI and skin surface measurements. Between the lumbar vertebrae and the skin there is often fat tissue which results in lower curvature results from skin surface measurement techniques.

Table 2-6 - Results of Mannion *et al* [19]

Parameter	Mean
T1-T12 Curve	45°
Thoracic RoM	25.6° < $\bar{x}$ < 29.8°
T12-S1 Curve	32°
Lumbar RoM	79°
Sacral Angle	19°
Sacral RoM	67°
Global Inclination	0.8° < $\bar{x}$ < 5.2°
Global RoM	142.1° < $\bar{x}$ < 145.4°

It can be seen that the mean T1 sagittal offset method of Vialle *et al* falls within the range of means found for global inclination by Mannion *et al*.

Förster *et al* [30] investigated the effect of regular climbing on the spine to determine whether climber's back was a bone-fide pathology. Climbers with climber's back supposedly have a humpback as well as rounded shoulders. 80 asymptomatic climbers had their thoracolumbar spines measured using the SpinalMouse®. The climbers were split into two groups depending on the number of hours per week that they trained. The results are outlined in Table 2-7. There was a significant difference between the two groups with the performance climbers having a larger thoracic curvature ($p < 0.01$). Given the description of climber's back and the results of this study there is a clear case for the existence of climber's back.

Table 2-7 - Results of Förster *et al* [30]

Parameter	Performance Climbers	Recreational Climbers
n	46	34
Training (hours/week)	9.8 (4.3)	3.4 (2.0)
T1-T12 Curve	48.4° (7.6°)	43.2° (6.7°)
L1-L5 Curve	28.9° (6.2°)	26.1° (8.1°)
Global Inclination	1.0° (1.8°)	0.2° (2.0°)

Leroux *et al* [31] measured 124 subjects under 19 years old who presented with scoliosis at a clinic. Each subject had two measurements taken, the first was a sagittal radiograph of the spine, the second involved reflective skin markers which were recorded by videography (see Section 3.7). The method used by Leroux *et al* to measure the curvatures of the thoracic and lumbar regions is similar to the method used by D'Osualdo *et al* but is more representative of the actual spinal curvatures (see Section 4.4). Table 2-8 shows the results of the study. The results from this study are lower than those from other studies for the thoracic range, however the subjects that took part in this study were children or young adults that had been diagnosed with scoliosis. Willner [21] showed that subjects with scoliosis had lower thoracic and lumbar curvatures.

Table 2-8 - Results of Leroux *et al* [31]

	X-ray Mean (SD)	Videography Mean (SD)
T2-T12 Kyphosis	33° (10°)	36° (12°)
T9-S1 Lordosis	52° (13°)	51° (17°)

Pearsall and Reid [20] investigated the centre of gravity as well as the thoracic and lumbar curvatures in asymptomatic 14 and 15 year old subjects using moiré topography. They found that the female subjects had significantly less thoracic curvature than the male subjects ($p < 0.05$) and more curvature in their lumbar spines (see Table 2-9). They also found that the line of gravity in the female subjects passed more anteriorly to the vertebral bodies than in the male subjects.

Table 2-9 - Results of Pearsall and Reid [20]

	Male Mean (SD)	Female Mean (SD)
T1-T12 Kyphosis	29.5°	23.0°
L1-L5 Lordosis	25.6°	30.8°

Willner [21] modified a pantograph in order to trace the sagittal spinal profile. In the study, 40 asymptomatic subjects and 15 subjects with scoliosis were radiographed and then had their sagittal spinal profiles recorded using the pantograph. The thoracic and lumbar curvatures calculated from the pantograph tracings were compared to the Cobb angles calculated from the radiographs. The results show that both the thoracic and lumbar curvatures are reduced in the subjects with scoliosis and that the thoracic measurements taken with both techniques yielded similar results (see Table 2-10). However, the lumbar curvatures calculated from the spinal pantograph tracings were significantly smaller ($p < 0.05$) than the lumbar curvatures calculated from the radiographs for both the asymptomatic subjects and the subjects with scoliosis.

Table 2-10 - Results of Willner [21]

Range	Technique	Asymptomatic Mean (SD)	Scoliosis Subjects Mean (SD)
T1-T12 Kyphosis	X-ray	40.9° (13.6°)	25.9° (10.1°)
Max. Kyphosis	Spinal Pantograph	39.7° (12.2°)	25.9° (9.3°)
L1-L5 Lordosis	X-ray	48.0° (12.6°)	41.9° (10.5°)
Max. Lordosis	Spinal Pantograph	38.9° (11.0°)	33.7° (7.4°)

Stagnara *et al* [16] measured the thoracic and lumbar Cobb angles of 100 people from X-ray images. The vertebra which was tilted most from the horizontal was determined to be the end point of the thoracic curve and the start point of the lumbar curve. The thoracic curve was measured from T4 and the lumbar curvature was measured to S1. They found the thoracic Cobb angle to be 37° and the lumbar Cobb angle to be 50°. The standard deviations quoted in the study seem excessively high given the quoted ranges of the thoracic and lumbar curvatures and the almost normal distribution.

Lumbar Spine

The measurement of the lumbar spinal curvature to predict likelihood of low back pain is common. Steinberg *et al* [22] measured the lumbar spinal curvature of 464, 18-year-old male army recruits who were free from any low back pain at the time of the measurements. The measurements were made using X-rays of the subjects in a supine position. This is not the ideal position for this type of study as the spine is not loaded. Among other things, they measured and analysed the lumbar spine Cobb angle. They found that the subjects who had a lumbar curve Cobb angle which exceeded 40° were almost twice as likely to have experienced low back pain previously in their lives. From their experiment they calculated the average lumbar Cobb angle for all subjects as being 31.4°. For the subjects who had not experienced low back pain, average L1-L5 lumbar Cobb angle was measured as 30.2° and for the subjects who had experienced low back pain the average lumbar Cobb angle was measured as 32.5°.

Chernukha *et al* [32] state that normal lumbar lordosis changes with age. Table 2-11 summarises their findings, using the Cobb angle measurement (see Section 4.1) from superior L1 to superior S1 with the subject in the supine position

Table 2-11 - Results of Chernukha *et al* [32]

Age Range	Mean (SD)
1-10	39° (8°)
11-30	51.5° (9.5°)

Other studies of the same vertebral range are within one standard deviation of these results. Andersson *et al* [33] found that 21-44 year olds had a lumbar Cobb angle of 60°, while Stagnara *et al* [16] found that 20-29 year olds had a lumbar Cobb angle of 50°.

Crawford *et al* [34] investigated the effect of interspinous implants on the lumbar spine. The implants are designed to ease back and leg pain however there are reports suggesting that it alters posture. Crawford *et al* measured 20 subjects; 10 asymptomatic subjects and 10 subjects that received implant surgery using rasterstereography (a technique which can generate a 3D computer model by detecting the patterns that horizontal lines of light create as they strike a surface, see Figure 2-6).

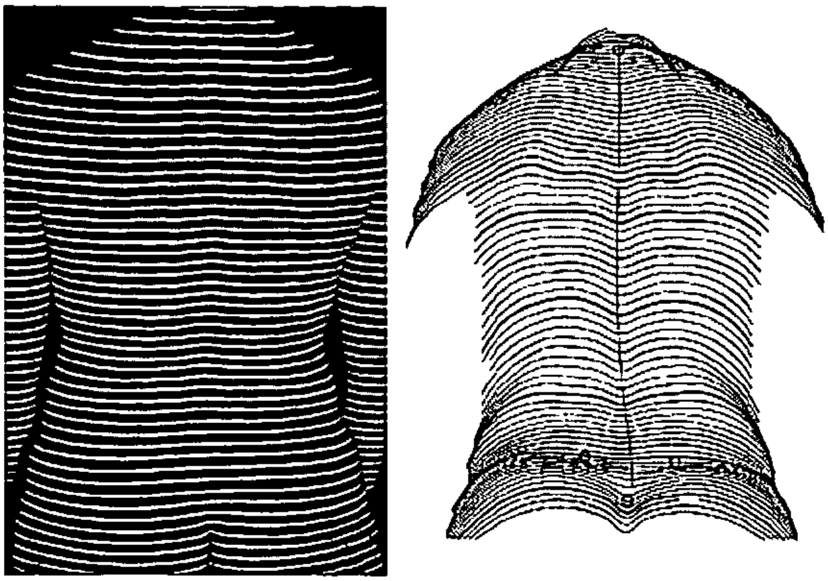

Figure 2-6 – Rasterstereography[1]

The surgery subjects were first measured pre-operation and then 6 weeks post-surgery while the asymptomatic subjects were measured once and then 6 weeks later. The surgery subjects were also X-rayed within an hour of the rasterstereographs being taken. Results are shown in Table 2-12. Significant differences before and after surgery were seen between the X-ray measurements ($p < 0.01$) and between the rasterstereograph measurements ($p < 0.05$) of the surgery subjects. The difference between the asymptomatic subjects was not significant. The results show that there is a reduction in lumbar lordosis caused by the implant and that rasterstereography is a non-radiological and reproducible measurement technique.

[1] Image from Crawford *et al* [34]

Table 2-12 - Results of Crawford *et al* [34]

Parameter	Asymptomatic Subjects	Surgery Subjects
Rasterstereography Measurement 1	46.0° (1.1°)	46.2° (0.9°)
Rasterstereography Measurement 2	45.4° (0.9°)	43.2° (0.7°)
X-ray Measurement 1	-	56.4° (10.7°)
X-ray Measurement 2	-	53.5° (12.1°)

Table 2-13 and Table 2-14 summarize the curvature results of the studies in this literature review. The mean values of thoracic curvature vary considerably for asymptomatic subjects; the minimum mean curvature is 23° and the maximum mean curvature 48.4°. The table clearly shows how measurement technique, range and the subjects affect the result and how difficult it is to compare results unless all the parameters are the same. The mean lumbar curvature of asymptomatic subjects varies between 25.6° and 60.2°.

Table 2-13 - Thoracic Curvature Results

Author	Angle Mean (SD)	Subjects	Vertebral Range	Method	Analysis Method
D'Osualdo *et al* [24]	37°-39°	Kyphosis/ Scoliosis	Max*	Arco-meter	Arc angles
D'Osualdo *et al* [24]	37°-42°	Kyphosis/ Scoliosis	Max*	X-ray	Arc angles
Förster *et al* [30]	43.2° (6.7°)	Casual Climbers	T1-T12	Spinal Mouse	Spinal Mouse
Förster *et al* [30]	48.4° (7.6°)	Sports Climbers	T1-T12	Spinal Mouse	Spinal Mouse
Harrison *et al* [18]	33.3°	Asympto-matic	T3-T10	X-ray	Cobb
Harrison *et al* [18]	44.2°	Asympto-matic	T1-T12	X-ray	Cobb
Harrison *et al* [18]	39.9°	Asympto-matic	T2-T11	X-ray	Cobb
Leroux *et al* [31]	36° (12°)	Female Scoliosis	T2-T12	Video-graphy	Alt. Arc Angles
Leroux *et al* [31]	33° (10°)	Female Scoliosis	T2-T12	X-ray	Alt. Arc Angles
Mannion *et al* [19]	45°	Asympto-matic	T1-T12	Spinal Mouse	Spinal Mouse
Pearsall *et al* [20]	29.5°	Young Male	T1-T12	Moire Topo-graphy	Arc Angles
Pearsall *et al* [20]	23°	Young Females	T1-T12	Moire Topo-graphy	Arc Angles
Stagnara *et al* [16]	37°	Asympto-matic	T4-End#	X-ray	Cobb
Vialle *et al* [3]	40.6° (10°)	Asympto-matic	T4-T12	X-ray	Cobb
Vialle *et al* [3]	41.2° (10°)	Asympto-matic	Max*	X-ray	Cobb
Willner [21]	25.9° (9.3°)	Scoliosis	Max*	Spinal Panto-graph	Skin Tangents
Willner [21]	39.7° (12.2°)	Asympto-matic	Max*	Spinal Panto-graph	Skin Tangents
Willner [21]	40.9° (13.6°)	Asympto-matic	T1-T12	X-ray	Cobb
Willner [21]	25.9° (10.1°)	Scoliosis	T1-T12	X-ray	Cobb

* 'Max' is the maximum amount of curvature on a per subject basis
# 'End' is where the thoracic curve is deemed to have ended on a per subject basis

Table 2-14 - Lumbar Curvature Results

Author	Angle Mean (SD)	Subjects	Vertebral Range	Method	Analysis Method
Förster *et al* [30]	26.1° (8.1°)	Casual Climbers	L1-L5	Spinal Mouse	Spinal Mouse
Förster *et al* [30]	28.9° (6.2°)	Sports Climbers	L1-L5	Spinal Mouse	Spinal Mouse
Leroux *et al* [31]	51° (17°)	Female Scoliosis	T9-S1	Video-graphy	Alt. Arc Angles
Leroux *et al* [31]	52° (13°)	Female Scoliosis	T9-S1	X-ray	Alt. Arc Angles
Mannion *et al* [19]	32°	Asympto-matic	T12-S1	Spinal Mouse	Spinal Mouse
Pearsall *et al* [20]	30.8°	Young Female	L1-L5	Moire Topo-graphy	Arc Angles
Pearsall *et al* [20]	25.6°	Young Males	L1-L5	Moire Topo-graphy	Arc Angles
Stagnara *et al* [16]	50°	Asympto-matic	Start#-S1	X-ray	Cobb
Steinberg *et al* [22]	30.2°	18 Year Old Males Previous Backpain	L1-L5	Supine X-ray	Cobb
Steinberg *et al* [22]	32.5°	18 Year Old Males No Previous Backpain	L1-L5	Supine X-ray	Cobb
Vialle *et al* [3]	43° (11.2°)	Asympto-matic	L1-L5	X-ray	Cobb
Vialle *et al* [3]	60.2° (10.3°)	Asympto-matic	Max*	X-ray	Cobb
Willner [21]	33.7° (7.4°)	Scoliosis	Max*	Spinal Panto-graph	Skin Tangents
Willner [21]	38.9° (11.0°)	Asympto-matic	Max*	Spinal Panto-graph	Skin Tangents
Willner [21]	48.0° (12.6°)	Asympto-matic	L1-L5	X-ray	Cobb
Willner [21]	41.9° (10.5°)	Scoliosis	L1-L5	X-ray	Cobb

* 'Max' is the maximum amount of curvature on a per subject basis
# 'Start' is where the lumbar curve is deemed to have started on a per subject basis

2.3.2 Standing on Gradients or in High Heeled Shoes

Previous research in the literature has highlighted that standing in high heeled shoes has similar effects to standing on a declined surface. Opila *et al* [35] used a motion analysis system consisting of retro reflective markers, standard markers and four tracking cameras to monitor the posture of subjects wearing high heeled shoes. They found that in females, the lordosis of the lumbar spine was reduced when subjects wore high heeled shoes. Franklin *et al* [36] assessed posture using a 3D co-ordinate skin surface measurement machine (Metrecom Skeletal Analysis System, Faro Technologies, Inc. FL, USA) which was run over the subject's back to generate co-ordinate data. They found that the wearing of heeled shoes significantly lowered the sacral base angle and like Opila *et al* [35] found that the amount of lumbar lordosis is also reduced. Lee *et al* [37] examined trunk flexion angle changes in women wearing different pairs of high heeled shoes. They found that trunk flexion angle decreased by 1° for each cm that the height of the heels increased. They also investigated the vertical increase in the centre of body mass due to the heels and the change in posture. This movement in the centre of body mass has been previously examined by Joseph and Nightingale [38] who observed an anterior movement of the centre of body mass when wearing high heeled shoes. This movement of the centre of body mass was hypothesized to explain the increased activity in the calf muscles.

The study by Lee *et al* [39] observed the changes in the lumbar curvature and the centre of body mass caused by wearing high-heeled shoes. The lumbar curvature was measured using photographs of five young healthy women wearing three different types of shoes: a pair of flats and two pairs of heeled shoes with the heels measuring 4.5cm and 8cm. The lumbar curvature was calculated using a method which uses three markers placed as shown in Figure 2-7.

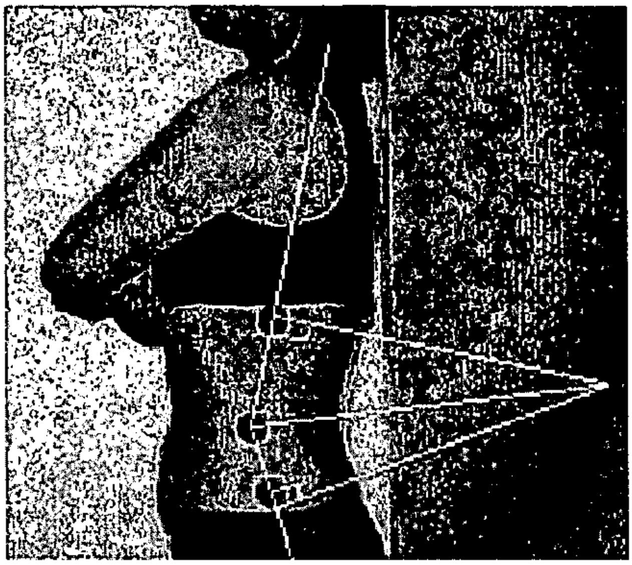

Figure 2-7 - Yoo's [40] Method for Measuring Lumbar Angle[1]

They found that as heel height increased, the lumbar curvature angle decreased. They believed that this was compensatory due to the anterior movement of the centre of body mass giving a feeling of falling forward as described by Snow & Williams [41] and Joseph and Nightingale [38]. They also found that EMG activity increased at the L4/L5 level as the heel height increased.

Kluzik *et al* [42, 43] looked at the effect on posture of increasing the surface gradient on which subjects, that they had deprived of sight and hearing, were standing. The surface gradient was increased up to 5° held and then returned while the trunk lean was recorded. Two groups of subjects were identified, those who lean forward, averaging a trunk lean of 5.6° (1.5°) and those that remain upright.

Studies by Mihcin and Acar [44], Shin and Mirka [45] and Zhao *et al* [46] have focused on the effects on the spine when lifting on differently inclined surfaces. The study by Mihcin and Acar [44] investigated the stability of the spine as an injury mechanism as a subject stood on differently inclined surfaces. They found that as the surface angle

[1] Image from Lee *et al* [39]

increases, instability of the spine increases. Shin and Mirka [45] observed the trunk flexion angle of 13 different subjects while performing one of three different lifting techniques at surface inclinations of 0°, ±10° and ±20°. They found that as the surface inclination angle increases the trunk flexion angle also increases. Therefore, subjects are more upright on a downhill slope than on an uphill slope. Zhao *et al* [46] observed the potential for slipping on surfaces inclined up to 25°. They concluded that perception of risk altered the posture of the subjects.

A number of studies have focused on walking on surfaces of different gradients. Leroux *et al* [47] compared standing and walking postures on surface gradients of 0, ±5 and ±10%. They found that when subjects were walking uphill, as the surface gradient was increased, the subjects increased their trunk angle and when the surface gradient was decreased so that the subjects were walking downhill, the subjects decreased their trunk angle. However, they found no changes in trunk angle between the different gradients when the subjects were standing. Similarly, Vogt and Banzer [48] observed the differences between walking on the horizontal and on a 10% incline. They also found that there was more flexion in the trunk when walking up an inclined surface. Prentice *et al* [49] examined how the body adapted while walking from a horizontal surface onto surfaces inclined at 3, 6, 9 and 12 degrees. They found small but significant increases in the forward inclination of the trunk.

Leroux *et al* [50] investigated the walking trunk inclination in the sagittal plane of eight subjects with spinal cord injuries (SCI) against eight healthy matched subjects. The subjects all had an impairment level of 'D' on the American Spinal Injury Association (ASIA) scale; four of the SCIs were caused by traffic incidents, two were caused by scuba diving incidents, one was from a fall and one was caused by a virus. All SCI subjects could walk on an inclined treadmill unaided. They measured the subjects on a treadmill, which could be inclined and declined up to 5.7° (10%), using skin markers and high resolution cameras. The trunk segment was defined to be from the C7 vertebra to the L3 vertebra. Subjects completed two measurement phases, the first measurement phase was static walking posture (standing with one foot in front of the other as though walking) the second was active walking. They found that when actively walking all subjects would lean forward. The SCI subjects had an overall higher level of trunk inclination for each surface. However, as the surface inclination increased the trunk inclination of the healthy subjects started to approach the trunk inclination of the SCI subjects. When in static walking posture there were no differences caused by surface inclination. The SCI subjects had a negative trunk tilt on average whilst the healthy subjects had a positive trunk tilt on average for all surface angles.

Spinal inclination has been shown to be affected by the range of motion of the ankle and the amount that the gastrosoleus complex and hamstrings can stretch. Sepic *et al* [51] found that there was little difference in ankle range of motion between genders. However, a study by Nigg *et al* [52] found that although males and females have similar total ankle range of motion, females have a lower dorsiflexion range and a higher plantar flexion range. Dorsiflexion is the upward movement of the foot, i.e. moving the foot towards the shin. Plantar flexion is the movement of the foot in the opposite direction.

2.4 Spinal Disorders

There are many spinal pathologies that affect people today. The following disorders are all related to the curvature of the spinal column or the range of motion of the vertebrae. Many of these spinal disorders are currently diagnosed using Cobb angle analysis on radiographs or MRI scans. However, with the risks associated with X-rays and the problems of MRI, skin surface techniques and their corresponding analysis techniques are viable alternatives. Studying how these disorders are measured and quantified aids investigations into posture changes. Also, knowing how these disorders affect subjects is useful in knowing how it would affect asymptomatic subjects if they were to adopt a similar posture.

2.4.1 Kyphosis

Kyphosis of the spine occurs in the thoracic spine. It is an exaggeration in the sagittal plane of the normal kyphotic curve. Many sources define kyphosis as the thoracic spine having a Cobb angle greater than 50° [53] (see Section 4.1); although, there is no consensus. Kyphosis can be:

- congenital
- caused by spinal injury (as in the instance of a compression fracture in the vertebral body)
- caused by abnormal vertebral growth
- caused by vertebral wedging in the case of Scheuermann's kyphosis
- caused by intervertebral discs losing water as a result of people getting older
- caused by osteoporosis in women
- caused by chronic contractions within muscles

Willner [21] found that the mean thoracic curve Cobb angle of people with Scheuermann's kyphosis was 22° greater than the mean thoracic curve Cobb angle of asymptomatic people. Kado *et al* [29] found that older males are more likely to have kyphosis than older females.

2.4.2 Lordosis

Lordosis is an exaggeration of a lordotic curve in the sagittal plane. It usually occurs in the lumbar spine, however, it can develop in the cervical spine. Lordosis can be caused by [54]:

- achondroplasia

- discitis
- the lumbar spine compensating for an exaggerated kyphotic thoracic spine
- obesity as the individual will lean back to improve balance
- osteoporosis in women
- posture
- spondylolisthesis (where a vertebra has slipped forward in relation to the other vertebrae)

Lumbar lordosis is not usually treated as it is generally a secondary problem caused by the lumbar spine compensating for another problem which is causing imbalance. If the underlying problem is treated then generally the lumbar spinal curve will return to normal. Changes in posture and certain exercises can also help lordosis sufferers regain a normal lumbar spinal curve.

2.4.3 Scoliosis

Scoliosis is a lateral curve of the spine which can occur anywhere from the lower neck to the base of the lumbar spine. Normally there is no curve of the spine in the lateral plane when a person stands erect. Scoliosis can become more complex if the person has kyphosis as well (kyphoscoliosis) or if some of the vertebrae have twisted about the superior/inferior axis running through the vertebral bodies of the spine. Scoliosis can be broken down into two main types, structural and non-structural. Structural scoliosis is where the spine has an abnormal structure. This abnormality could be idiopathic, congenital, post-traumatic or caused by disease (neuromuscular or metabolic).

Non-structural (or functional) scoliosis is caused by a secondary, underlying problem such as leg length discrepancies, inflammations or spasms. Non-structural scoliosis is often resolved when the secondary problem is treated.

A scoliosis screening consists of an examiner looking for asymmetries of the body. For example when the patient is standing erect and the examiner is observing from behind, the spine does not look straight or the shoulders/shoulder blades are lop-sided. When the patient is asked to bend forwards, one of their shoulder blades will be more prominent. An X-ray is used to confirm diagnosis. The lateral curve, obtained from the X-ray, is measured using the Cobb (see Section 4.1) angle measurement technique. Scoliosis is defined to be a lateral curve of the spine, having a Cobb angle of at least 10°. The majority of scoliotic curves have a Cobb angle of 10°-40°. Mild and moderate scoliosis (curves with a Cobb angle less than 90°) is not associated with constant pain or physical limitation. However, severe scoliosis (90° and greater) can affect the cardiopulmonary system and the patients physical appearance.

Observation, bracing and surgery are available to patients diagnosed with scoliosis, depending on the amount and rate of progression of the curvature [55, 56, 57, 58].

2.4.4 Slipped and Herniated Discs

Slipped disc is the term for when a disc has been compressed too much - although not to the point of herniation - and has caused the outer wall of the disc to bulge into the vertebral canal. The bulge will often compress the spinal cord or a nerve root (where a nerve exits the spinal canal) causing the person pain. The most common sites for disc problems are at C5/6, L4/5 and at L5/S1 [59].

A herniated (burst) disc is a disc where the nucleus of the disc has broken through the outer wall of the disc and is compressing part of the spinal cord or a nerve root [60]. Sciatica is a form of herniated disc where the sciatic nerve root is being compressed by the burst disc. The compression of the sciatic nerve causes pain down the back of the upper legs. Sciatica generally results in a change in posture.

These disorders would usually be diagnosed from the patient's description of the pain and possibly confirmed by the patient having an MRI. The patient's range of motion is likely to be affected as movement may be painful to the patient. Also, it is possible that the patient's normal posture may alter due to the pain caused by the disc. A skin surface technique that measures range of motion could be used to monitor a patient's rehabilitation.

2.4.5 Hypo/Hypermobility

The term hypo vertebral segment refers to the condition where a vertebral segment is too stiff. The term hyper mobile vertebral segment refers to the condition where a vertebral segment is too mobile. Hypo and hypermobility can be assessed using individual intervertebral ranges of motion, i.e. examining the amount that each vertebra can move. This can be done by overlaying X-rays of a subject in an extended posture and in a flexed posture. The manufacturers of the SpinalMouse® device (see Section 3.3) claim the device can be used in preliminary diagnosis as it can identify any rapid changes of spinal curve as well as areas where there is little movement between adjacent vertebrae.

2.4.6 Spondylolisthesis

Spondylolisthesis describes a disorder where a vertebra has slipped forward with relation to the other vertebrae in the spinal column. It usually occurs in the lumbar spine. It is generally discovered by having a lateral radiograph taken of the lower spine. Spondylolisthesis occurs mainly in adolescents, especially in athletes involved in sports which hyper-extend the spine such as throwing [61]. It is not known why some athletes involved in sports which hyper-extend the spine develop spondylolisthesis whereas others do not. Spondylolisthesis can also occur in older adults due to degeneration in the discs and the facet joints. This degeneration can allow a vertebra to slip with or without fracture. Treatment can include bracing, various controlled exercise regimes and in severe cases, surgery. Retrolisthesis describes a vertebra which has slipped backwards with respect to the other vertebrae in the spinal column.

2.4.7 Acute and Chronic Back pain

Back pain is a serious problem. In the US it is one of the most common reasons for lost work hours and visits to the doctor [9, 10]. Bupa® [11] claim that 95% of back pain in the UK is acute back pain, that is, back pain that is only temporary and is due mainly to the way that the bones, ligaments and muscles of the back are working together. The pain could be caused by damage to any of the elements of the back. This type of back pain usually heals itself, within a few days up to a few weeks, without the need for tests or surgery. Chronic back pain is back pain lasting for more than three months.

2.4.8 Flat back syndrome

Flat back syndrome is when there is a lack of curvature of the spine. It is usually associated with people that have had corrective surgery before it was realised that surgery could reduce the kyphotic/lordotic curve by too much. New methods in surgery have now made this spinal disorder much less common. Skin surface techniques could be used in preliminary diagnosis of this disorder and possibly to gauge the effectiveness of corrective surgery/therapy to restore a normal curvature

2.4.9 Obesity

Obesity or a high body mass index (BMI) can result in a person's posture changing such that it causes them pain. In general it is the lumbar spine that undergoes changes in order to correct the imbalance that the excess weight has caused [54]. A person's BMI is calculated as the person's weight in kilograms divided by their height in metres squared. This usually gives a number between 15 and 40 kg/m^2. There are many different views on the range of healthy, overweight and obese BMIs but the World Health Organization's (WHO) [62] figures, which are internationally recognised are given in Table 2-15.

Table 2-15 - WHO BMI Classifications [62]

Lower Boundary	Category	Upper Boundary
	Underweight	20
20	Healthy	25
25	Overweight	30
30	Obese	

The BMI measure does not take into account all variables. Individuals with high percentages of muscle mass such as athletes and body builders will have a high BMI but should not be classed as obese. Conversely, elderly people that have low muscle and bone mass may have healthy BMIs but may actually be obese. The figures quoted in Table 2-15 only reflect on adult BMIs. For children, a percentile figure is used to classify obesity. A BMI that is less than the 5^{th} percentile is considered underweight and above the 95^{th} percentile is overweight. Children with a BMI between the 85^{th} and 95^{th} percentile are considered to be at risk of becoming overweight. Finally, BMI does not take into account the nationality of the person, for example, the ranges for Asians are generally shifted by $-2\ kg/m^2$. Generally, the actual physical change to the spine is that the lumbar spine curve becomes more exaggerated. As such, a measurement of a person's BMI and a skin surface measurement of the lumbar spine could highlight a possible connection between a person's back pain and their weight.

Another factor to consider is where the excess fat is deposited. Fat located abdominally will affect the lower back as more weight has to be supported by the spine and its muscles. Fat deposited on the hips will affect the pelvic alignment which can alter balance thus the lumbar spine corrects the imbalance by becoming more curved. Obese individuals generally exercise less and as a result the back muscles can atrophy and become weaker and more prone to injury. Obese individuals also place more load on the intervertebral discs potentially causing the disc to herniate or degenerate. Obesity can also cause spondylolisthesis (see Section 2.4.6).

2.5 Patient Self Assessments

It is often useful when diagnosing patients to know how their back pain affects their lives. This can sometimes be a key point in discovering their pathology. A study by Leclaire *et al* [63] found that the Roland-Morris and the Oswestry disability scales could be used to distinguish between those with low back pain and those with radiculopathy (a disease of the spinal nerve roots). Although these methods do not measure either the spinal curvature or the range of motion, they can provide information on the true severity of the pain. As they provide a numerical result, pain boundaries can be established and used in comparison studies. There are many patient self assessment tests available some of them are purely yes/no answered, others have ordinal options as responses and some have visual analogue scales. Some of them include a combination. Visual analogue scales (VAS) are generally a uniformly marked scale between zero and ten. The patient places a mark on the scale at the point where they rank their answer. It would be difficult to use VAS to compare two patients as pain and disability are subject specific. Questions with ordinal answers are a better way to compare inter-patient but specific progress cannot be measured as easily. Only when a patient crosses from one answer to another can progress be measured. However, progress may seem to take much longer. Nominal answers cannot be over exaggerated which would imply that questionnaires such as Roland-Morris are possibly a better test to measure inter-patient. A patient that might be receiving compensation may make out a higher level of suffering; whereas a patient who wants to be discharged may indicate a lower level of suffering. It also depends on the patient's pain threshold which is different for everybody. Obviously patients can also lie on a questionnaire.

2.6 Conclusions

Many of the studies reviewed have attempted to reduce the curvature of each section of the spine to a number, be it a ratio or an angle. This allows for easy comparison between measurements (inter-subject and intra-subject) and allows for normal ranges and critical values to be defined. However, there is a wide range of values for asymptomatic spinal parameters in the literature. Humans are all different from each other so a range of values is needed to define normal parameters; however, the range is widened due to the different measurement techniques available to researchers.

Current studies have generally focused on measuring one or two parameters however the spine is a system, changes in one area affect the other areas [1]. Also, many studies provide ranges and analysis for all subjects rather than separating male and female results. There have been numerous studies which have focused on the spine when subjects are standing on horizontal ground but far fewer studies have focused on when subjects are standing on gradients and to date no known studies have focused on wearing heeled footwear on a gradient. An experiment which uses the same measurement device to measure a number of spinal parameters of subjects standing on different surface gradients and in different footwear is proposed. The experiment will also compare the differences between how males and females adapt to these 'environments'. Previous studies focusing on the effects of gradients on the spine are generally female orientated as a declined surface is deemed to be synonymous with wearing heeled footwear. This should also be investigated. Decisions need to be made as to which measurement technique(s) to use and how to analyse the results. Chapters 3 and 4 detail the current spinal measurement techniques and measurement analysis techniques.

Chapter 3 - Spinal Measurement Techniques

In order to conduct research into the changes in posture caused by heeled shoes and non-horizontal surfaces suitable measurement and analysis techniques are required. This chapter outlines a number of the possible options of measuring the spinal column's curvature.

There are numerous methods to assess the condition of the spine. Non-invasive methods are preferable as they do not violate the subjects' bodies. X-rays and Magnetic Resonance Imaging (MRI) scans are the current methods used to diagnose most spinal pathologies as they allow the examiner to observe the vertebral positions and alignment. Although non-invasive, X-rays use ionizing radiation and MRI scanners are very expensive and each scan is time consuming. Both X-rays and MRI scans require licensed technicians and are not suitable for everyone.

Skin surface techniques are used to assess the curvature of the spine and to observe spinal range of motion. The magnitude of curvature and the extent of the range of motion are able to diagnose certain pathologies. Generally, skin surface measurement techniques use less expensive, smaller and more portable equipment, are quicker in measuring the subject and do not require a specialist to operate them. As well as being non-invasive, skin surface techniques do not expose the subject to radiation. These reasons lead skin surface techniques to being good candidates for use as screening and monitoring tools. However, external obstructions such as tumours and fat-tissue can impair the results.

By using non-radiological methods and not exposing subjects to radiation, it is possible to conduct more tests on each subject should there be a need [55, 56]. This is very important when dealing with young subjects who are still growing and whose spinal curvature can change drastically in the period of just a year. Rather than subjecting these young people to multiple X-rays each year the number of required X-rays could be reduced to one in order to ascertain whether the vertebrae are forming properly and are not wedge shaped or fusing together.

3.1 X-rays

X-rays are used in radiographs/roentgenographs and computerized tomography/computerized axial tomography scans. They are useful for diagnosing spinal pathologies as they allow the radiographer to see the vertebrae and the arrangement without having to invade the patient (see Figure 3-1). Radiographs, also referred to as roentgenographs, are considered the gold standard in assessing spinal disorders.

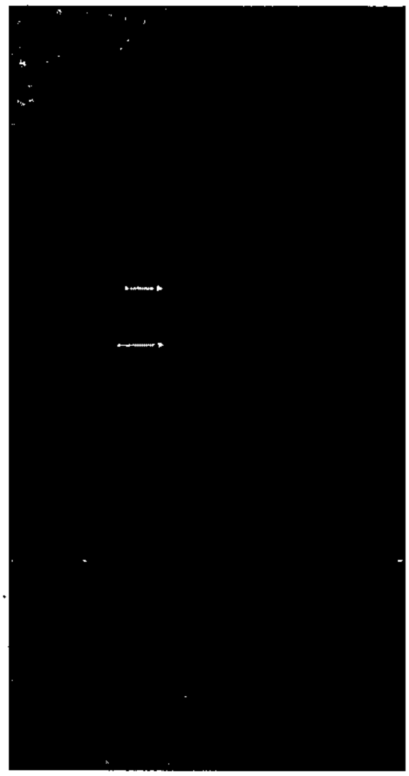

Figure 3-1 - Thoracic Radiograph[1]

Despite X-rays being the gold standard, any technique that subjects the patient to X-ray radiation is harmful to that patient and is not advisable if

[1] Fritsch & Thompson. 2005. Lateral thoracic spine xrays showing calcification of T7-T8 disc. Retrieved on March 18, 2009, from http://www.mypacs.net/cases/THORACIC-HNP --IDIOPATHIC-DISC-CALCIFICATION-3205826.html

the patient is pregnant. As X-rays cause cell damage, alternative methods for obtaining spinal curvatures should be considered for anyone who is under observation and requiring regular radiographs to reduce X-ray exposure. Radiographs, although often necessary, are also not recommended for children and those that are still growing since cell damage caused by X-rays at this time is especially harmful. The spinal disorder scoliosis, characterised by one or two lateral curvatures of the spine (see Section 2.4), is generally monitored through the patient having radiographs. As most scoliosis sufferers are adolescents, their spines are still growing and as such need to be monitored through radiography regularly, so that the correct course of treatment can be administered depending on their skeletal maturity and the progression of the scoliosis. This results in them being subjected to regular radiographs at a time when they are very susceptible to the effects of the X-rays. Clearly this is undesired and as such investigations have been undertaken to investigate the seriousness of the effects and whether methodologies could be changed. The study by Almén and Mattsson [64] found that X-rays for scoliosis irradiated the highest number of radio-sensitive organs. The absorption dose to those organs however, was lower than the absorption dose of the organs irradiated in both thoracic and lumbar X-rays. Skeletal maturity can be gauged by observing the progress of fusion between the iliac crests and the ilium. To assess the skeletal maturity in this way, the iliac crests must be on the X-ray. There are two distinct methods of doing this; the first is using a wider and longer anteroposterior (A-P) X-ray so that the crests and the sacrum are on the same X-ray image as the rest of the spine. The second method, which was investigated by Almén and Mattsson, was to obtain a separate X-ray of the sacrum and the iliac crests. This method allows the X-ray of the rest of the spine to be optimised - in this case made thinner - to reduce the radiation absorbed by the organs in the thorax and abdomen. However, Almén and Mattsson recommend that an X-ray of the hand is taken to assess skeletal maturity, a method also suggested by Richardson [65] if the crests were not present on the A-P X-ray. In assessing the appropriateness of obtaining an X-ray of the iliac crests, an important point to consider is that the ovaries are exposed to radiation. As the ovaries are organs which will absorb a high percentage of radiation the risk of radiation induced ovarian cancer increases. As most adolescent scoliosis sufferers are female and are submitted for an X-ray possibly every six months, this method should be avoided if possible.

Computerized Tomography (CT) previously known as Computerized Axial Tomography (CAT) scans can provide significantly more information than traditional X-rays. Unfortunately this extra information comes at a cost to the patient as they receive a higher radiation dose, although, with each new generation of CT scanners the dosage received has been reduced. The patient lays down on a movable bed which can be moved through a circular opening in the CT scanner. The circular opening houses a movable X-ray source and an X-ray detector array. The source and detector array are located on opposite sides of the circular opening. The source emits a fan shaped beam which passes through the axial plane of the patient's body that is currently in the circular opening. The fan shaped beam reduces the time and amount of exposure to the patient. The source and detector array are then moved around the circular opening for the next part of the scan. Once a scan revolution (or half) is complete the patient is moved up/down to scan the next axial plane. This approach allows a volumetric computer model to be constructed.

As CT/CAT scans are performed with the patient in a supine position, the curves of the spine are not the same as when the patient is standing because the spine is not in a weight bearing state.

There are numerous problems associated with the readings of X-rays and CT/CAT scans mainly due to human error. Although they have the advantage of knowing the locations of the vertebrae the determination of vertebral landmarks and boundaries proves difficult both inter and intra-examiner. For purposes purely of experimentation it is unethical to ask people to have a radiograph or CT/CAT scan due to the radiation they would be exposed to. Also, both methods are not easily available and both require a licensed technician for operation.

3.2 Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI), which relies on magnetic resonance rather than X-ray radiation, is a safer alternative but is a much slower and more costly method. Typical MRI images take between 20 and 90 minutes, in which time the patients must remain as still as possible so as not to distort the image. An MRI image of the thoracic spine is shown in Figure 3-2.

Figure 3-2 - Thoracic MRI Image[1]

There are no known biological hazards to humans associated with MRI scanners used medically i.e. scanners which use magnets which have a

[1] Fritsch & Thompson. 2005. Right paramedium FSE T1 sagittal MR slightly right of midline shows HNP at the T8-T9 level. Retrieved on March 18, 2009, from http://www.mypacs.net /cases/THORACIC-HNP--IDIOPATHIC-DISC-CALCIFICATION-3205826.html

strength below 2 Tesla. Many facilities however, prefer not to scan pregnant women and care has to be taken when scanning patients with metallic objects inside of them, for instance metal fragments, aneurism clips, and orthopaedic hardware. If the metallic object is embedded within bone or scar tissue the patent can generally still be scanned. People with pacemakers cannot be scanned or be in the proximity of MRI scanners as the scanner can potentially cause malfunctions in the pacemaker. As the patient lies in the magnet's bore (a tunnel) this can be very distressing for people that are claustrophobic. Also, people that are quite large may not be able to fit inside the bore. There are spine surgeons that believe that spinal pathologies such as vertebral subluxation or vertebral slipping can be missed, as the patient is supine while having an MRI scan and as such the spine is in a non weight bearing state. However, a new breed of MRI scanners is now available from FONAR [66] which allow MRI images to be taken with the patient in upright, flexion, extension, supine, sitting and even in the position in which the patient feels the pain for which they are currently being diagnosed. These scanners also reduce the claustrophobic experience of normal MRI scanners as these scanners are open. Unlike CT scans which can only scan in axial planes, MRI scanners can scan in any plane of the body and construct very detailed 2D (tomographic) images and even 3D volumetric models. However, higher quality images require a stronger magnet and MRI scanners with stronger magnets are more expensive. MRI exams can be tailored specifically to what the radiologist is trying to find.

The images produced through MRI, like images produced radiographically, cause problems for examiners trying to determine the boundaries and landmarks of vertebrae. Other disadvantageous similarities between MRI and radiographic methods are the cost and the need for experienced technicians. However, MRI does not subject the examinee to radiation and with the advent of MRI scanners which are able to scan the patient in different positions they are able to view the spinal column in non-supine positions.

3.3 SpinalMouse®

The SpinalMouse® works by using two inclinometers arranged in orthogonal planes and an accelerometer. The combination of the two inclinometers in perpendicular planes allows the device to measure the angle to the vertical whether measuring in the sagittal or lateral planes. The accelerometer allows the device to measure the distance that the wheels of the SpinalMouse® have travelled over the subject's skin (see Figure 3-3).

Figure 3-3 - SpinalMouse® Measuring Technique[1]

[1] Aditus Systems. 2004. SpinalMouse® measurement. Retrieved on May 23, 2006, from http://://www.spinalmouse.com/

The data generated by the measurement are then sent to a computer via a serial port to provide a digital representation of the skin surface curve of the human spine. The hardware is quoted to have an angular measurement accuracy of 0.1° and distance measurement accuracy of 1mm. This makes it a highly accurate skin surface measurement technique.

Using the angle and the distance travelled, the software can construct line segments at the recorded angle for the recorded distance continuously. This continuous set of line segments form the spinal curve that the user sees on the screen. When the software is informed that the measurement is complete it then calculates where the spinous processes would be on the curve. The software algorithm used to actually calculate these positions is unknown and would not be released by the manufacturing company idiag™. At each point where the software calculates there to be a spinous process the angle is recorded. When the adjacent spinous process is found and the angle recorded the intervertebral angle is calculated (as the difference between the angles to the vertical of the two vertebrae). Once all the angles have been calculated, the results are displayed as a results table (see Table 3-1) and as a diagram of the spinal contours (see Figure 3-5).

Once all 17 intervertebral angles (T1/T2-L5/S1) are calculated the thoracic and lumbar spine section angles are calculated. According to the manual this is done simply by adding the intervertebral angles for Th1/2 to Th11/12 for the thoracic section of the spine and by adding Th12/L1 to L5/S1 for the lumbar spine section. The summation of intervertebral angles is not always equal to the thoracic/lumbar section result. However, this could be due to the rounding of angles. Alternatively, the angle to the vertical of the first and last vertebra of each spinal section can be compared. The software mainly focuses on providing the examiner with intervertebral angle measurements (see angle β in Figure 3-4) from Th1/2 down to L5/S1. Once a measurement in full flexion, upright and full extension, have been taken, three Ranges of Motion (RoM) in terms of differences between intervertebral angles are calculated by the software and displayed in a table, (see Table 3-1).

Table 3-1 - SpinalMouse® Output

Segment	Upr	Flex	Ext	U-F	U-E	E-F
Th1/2	10	14	10	4	0	4
Th2/3	-1	6	3	8	4	3
Th3/4	2	-1	2	-3	0	-3
Th4/5	0	5	5	5	5	0
Th5/6	2	5	2	2	0	2
Th6/7	6	3	4	-3	-2	-1
Th7/8	7	5	2	-2	-5	3
Th8/9	23	4	3	-19	-20	1
Th9/10	-9	20	21	29	31	-2
Th10/11	-1	2	0	3	2	2
Th11/12	-3	6	-3	9	0	9
Th12/L1	-5	2	6	6	11	-4
L1/2	-6	4	1	10	7	3
L2/3	-9	1	-6	10	4	7
L3/4	-13	3	-9	17	5	12
L4/5	-9	7	-5	16	4	12
L5/S1	-6	1	-5	7	1	6
Sac/Hip	35	63	-29	28	-64	92
ThSp	36	69	50	33	14	19
LSp	-48	17	-18	66	31	35
Incl	1	97	-33	96	-34	130
Length	489	549	467	60	-23	82

Upr - the intervertebral angles of the subject in an upright posture
Flex - the intervertebral angles of the subject in a flexion posture
Ext - the intervertebral angles of the subject in an extension posture
U-F - intervertebral flexion range of motion angles calculated as flexion measurement minus the upright measurement†
U-E - intervertebral extension range of motion angles calculated as extension measurement minus the upright measurement†
E-F - intervertebral full range of motion angles calculated as flexion measurement minus the extension measurement†
Sac-Hip is the sacral hip angle to the vertical
ThSp - the overall change in angle of the thoracic section
LSp - the overall change in angle of the lumbar section
Incl - the inclination of the line between T1 and L5
Length - the length of the curve of the spine

† These labels should probably be F-U, E-U and F-E respectively. However, they have been reproduced as the SpinalMouse® software labels them.

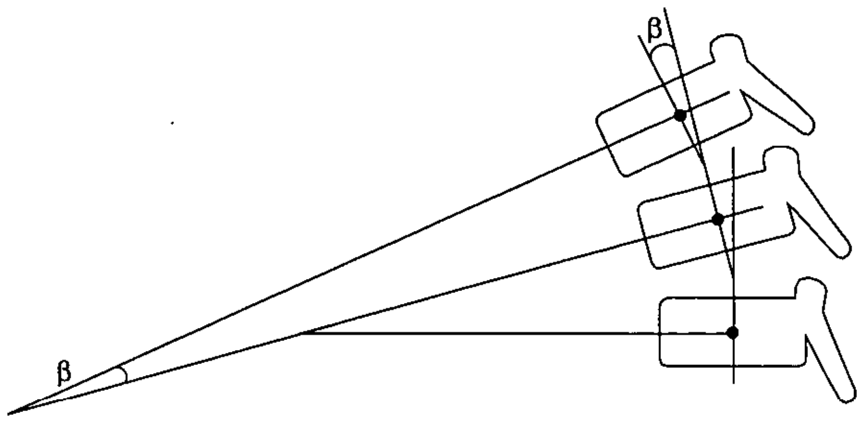

Figure 3-4 - SpinalMouse® Intervertebral Angles

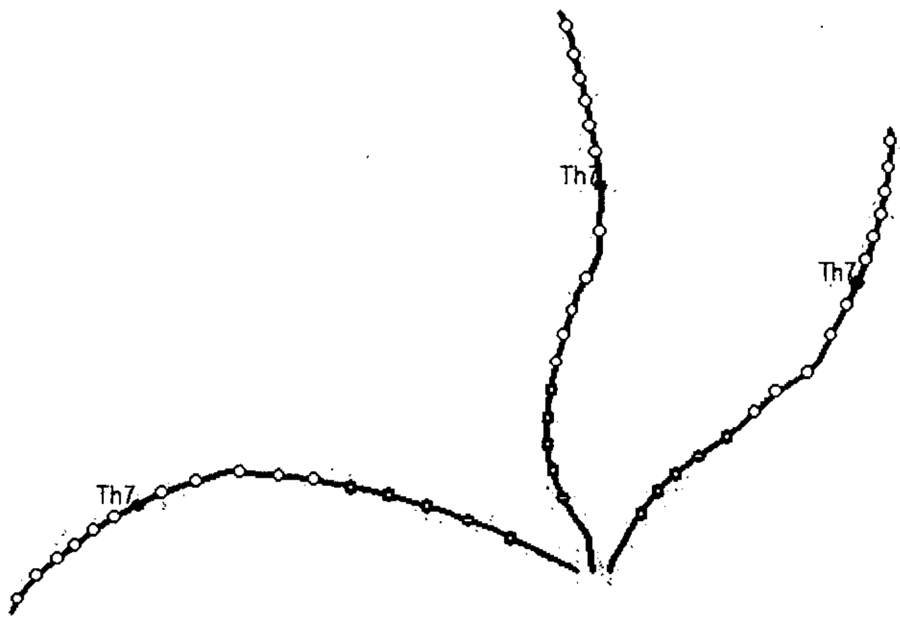

Figure 3-5 – Spinal Curves Displayed by the SpinalMouse® Software[1]

The Ranges of Motion (RoM) that are calculated are the upright-flexion, upright-extension and the flexion-extension. RoM can be used as a measure of spinal flexibility improvement by looking at the change in RoM over time. RoM can also be used to diagnose subjects with hyper/hypomobility. The SpinalMouse® is a useful tool for transferring spinal curvatures onto a PC so that the curvatures can be analysed. It can be used for gathering:

[1] Image from a cropped screenshot of the SpinalMouse® software

- Sagittal and lateral spinal measurements with the subject either standing or sitting down
- Tangential and distance measurements in a free mode to measure knees or elbows etc.
- Matthiass test results to observe spinal posture and stability

The software provides the following information:

- Intervertebral angles for T1 to L5 in the sagittal and lateral planes
- Range of motion for each vertebral segment between T1 and L5 in the sagittal and lateral planes
- Age and gender group values for range of motion to compare an individual's data to the group data
- The length along the surface of the back from T1 to L5
- The inclination of the T1 to L5 section of the spine
- The angle of the sacrum/hip to the vertical
- Tangents to curves at any point can be generated (only in free mode)
- The distance between any two points on the curve (only in free mode)

A disadvantage of using a skin-surface technique such as the SpinalMouse® is that the measurement boundaries have to be defined by palpitation which can be erroneous. Also, palpitation should be done with the subject in the position they are going to be in for the measurement; as markings made on the skin may not be in the same vertebral position due to the skin moving or stretching. Palpitation for vertebra such as the C7 vertebra is relatively easy due to the prominence of the spinous process. However, other vertebra are more difficult, especially the other cervical vertebra. For standard measurements made using the SpinalMouse® the problems of palpitation have been eliminated as the measurement starts at C7 and ends at S3 (the top of the anal crease). These are both easily and quickly identifiable by the examiner which is vital for measurements done when time is critical. For instance, progressive muscle fatigue may cause changes in the spinal curvature while the measurement is being carried out, which could lead to incorrect results.

3.4 Flexicurve

Several articles [27, 67, 68, 69, 70, 71] detail how the flexicurve can be used to measure spinal curvature. The flexicurve is a flexible piece of coated metal similar to a French curve. To use it, an examiner would press it paravertebrally against the subject's back so as to mould it to the same curvature. When this has been achieved, the curve is carefully removed and placed on a piece of paper where it is traced. In most studies, [27, 68, 69, 70] the subject's skin is palpitated and marked and then the corresponding point on the flexicurve is also marked so that reference points, usually the spinous processes, can be gained.

Although cheap, simple to use and free from side effects, the flexicurve does have problems. The flexicurve can lose some of its shape when being transferred from the subject's back to the paper for tracing. Also, when moulding the flexicurve onto to the subject's back the force required may alter the subject's posture. Although it takes only a few minutes to mould the flexicurve to the subject's spinal contour, if the subject's muscles are likely to become fatigued then the posture could alter while the measurement is taking place. Also, the subject's breathing can affect the contour measured and it would not be possible to ask the subject to hold their breath.

Caine *et al* [67] looked at ways of improving the measurements taken using a flexicurve and suggested mounting it to a rigid frame at three points so that:

- The flexicurve does not change its shape when being transferred from the subject's back onto the paper for tracing. When the flexicurve has been moulded into shape the paper used for tracing is attached to the frame alongside the flexicurve, so that the flexicurve is not moved at all.

- The pressure, which is required to mould the flexicurve into the shape of subjects' spines, does not cause the subject to change their posture, thus causing the wrong posture to be measured. By having the flexicurve suspended, less pressure needs to be exerted, reducing the possibility of changing the subject's posture. A compacted foam lining is fixed to the flexicurve which also apparently reduces the pressure required.

- The frame is attached by an adjustable means to a stadiometer (an instrument used for measuring the standing or sitting height of a subject). When the subject is first measured the reading of where the frame is on the stadiometer is taken. In subsequent measurements of the same subject, the frame is moved to the same position. This reduces the chance of placing the flexicurve in a different position each time a subject is measured.

Although these improvements produced more reliable results than most other similar studies, the portability of the flexicurve has been compromised.

A similar device to the mounted flexicurve can be seen in a study by Reynolds and Lovett [72] as well as at The Occupational Safety and Ergonomics Laboratory at Auburn University (see Figure 3-6). It is called the Spinal Curvature Measurement Device (SCMD) [73].

Figure 3-6 - Spinal Curvature Measurement Device[1]

It consists of a number of small slats of wood, all the same size, arranged in a vertical column, so that they can move in only one dimension (forward and backward). Along side them, mounted to the rear of the unit is a sheet of paper. A subject stands so that the slats of wood move in the subject's sagittal plane, and when they are moved forwards they make contact with the subject just slightly to the left/right of the subject's spinous processes (paravertebrally). At the other end of the slats of wood where the paper is mounted the examiner will be able to transfer the shape of the subject's back surface onto the paper by drawing a line down against the slats of wood. Given the similarities with the mounted flexicurve this device would have the same advantages and disadvantages.

3.5 Spinal Pantograph

The spinal pantograph is similar to an artist's pantograph only orientated vertically rather than horizontally and with the tracer and the marker switched. Figure 3-7 shows a diagram of the spinal pantograph; Point D is the anchor point fixed to a framework, Point F is the tracer which is run

[1] Image from Auburn University's website [73]

down the subjects' spine, Point E is the marker which draws the spinal contour on the paper.

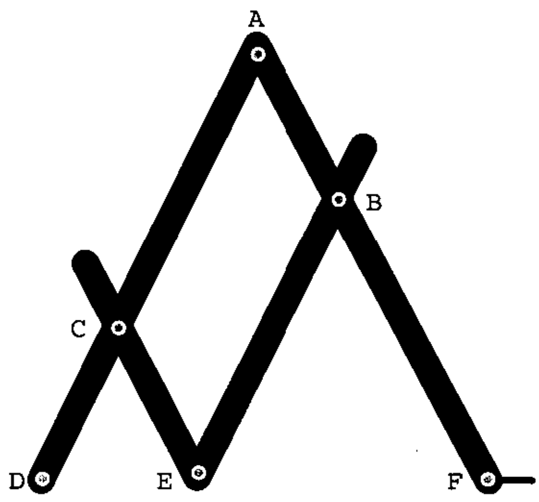

Figure 3-7 - A Pantograph

Like an artist's pantograph, a spinal pantograph traces and scales the sagittal spinal contour. The spinal pantograph has been used by Willner [21, 74] to evaluate both kyphosis and lordosis and compare these methods to X-rays. His studies claim that there is a statistically significant correlation between the spinal pantograph measurements and X-ray measurements. However, in lumbar lordosis an underestimation is observed in using the results from the spinal pantograph.

Although the spinal pantograph is fairly portable and measurements would seem to be able to be taken quite quickly it can only measure the contour when the subject is standing upright.

3.6 Arcometer

The arcometer is a device used for measuring the angle of curvature. It was created at the Engineering Faculty at Udine University, Italy. D'Osualdo *et al* [24] compared measurements of the degree of kyphosis between the arcometer and radiographs. They also carried out inter and intra-rater testing on the arcometer.

The arcometer is constructed as shown in Figure 3-8. The central horizontal bar is a millimetre scaled ruler which can be moved in both the vertical and horizontal planes. The pad at the base of the central rod is placed on the most posterior part of the kyphotic curve. The top horizontal rod is fixed and placed at the apex of the kyphotic curve. The vertical bar is also millimetre scaled and the bottom horizontal rod can be moved along it so that its pad is at the base of the kyphotic curve. The reading on the vertical bar is the chord length and the reading on the central horizontal bar is the arc rise. With these two readings the examiner can calculate the angle of curvature. Although Leroux *et al* [31] used videography and skin markers, the arcometer can provide the required data to calculate their (double) angle of curvature (see Section 4.4).

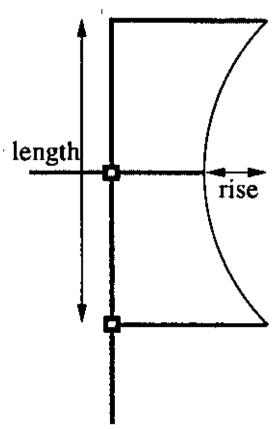

Figure 3-8 - The Arcometer

The arcometer is a portable and simple device to use. It seems that the measurements need to be read off of the arcometer while it is still in place on the subject; therefore increasing the amount of time per measurement. Also as measurements are read off they could be misread or misheard. For quantifying certain curvatures such as the complete thoracic curvature, the examiner would need to know the vertebral locations which would have to be estimated by palpitation, another time consuming task. Clearly this is not practical when muscle fatigue could be altering the subject's posture. Finally, the contact surface of the pads which rest upon the subject's spine look to be two centimetres long, which will reduce the accuracy of this measurement tool.

3.7 Skin surface markers

Skin surface markers come in varying shapes and sizes. For sagittal profile measurements where angles are being measured a lightweight rod with two pieces of radiographic/reflective tape around it is used so that an angle to the horizontal/vertical can be calculated [75, 76]. The markers are usually placed perpendicularly to the surface of the skin [76] although not all studies make it clear that this is the case [75]. If only positional data is required, spherical markers can be attached to the skin [37]. For lateral positional measurements a circular piece of radiographic/reflective material is generally used [31]. This is attached to the skin purely to note the position of the marked point relative to other marked points. The position and orientation of the markers are usually recorded using photography or videography. In comparison studies radiographic tape/markers will be used as they will show up on X-rays so that it can be seen where the markers were placed relative to the vertebrae [75].

As these markers are attached to the skin, and as the skin moves and stretches, they may not be marking what they were originally meant to be marking while the measurement is taking place. This is not always a significant problem for instance if the markers are not meant to be marking vertebral landmarks. Skin surface markers have the added benefit of allowing the examiners to view the changes in the curvature of the spine while a subject is moving or performing a motion for instance lifting or walking. Although the set up time is lengthy, the measurements can be performed real time.

3.8 Inclinometers and Goniometers

These are similar devices used to measure the angle to the vertical when placed on a surface - such as a subject's spine (see Figure 3-9). Thomas *et al* [77] used an inclinometer to measure spinal extension. This measurement requires that markings are made on the subject 5cm below the lumbosacral junction and 10cm above the lumbosacral junction. These markings are made with the subject standing fully erect. The subject then leans back as far as possible (extension) and the inclinometer is used to measure the angular difference between the two markers. This measurement technique is often used in diagnosing subjects with limited ranges of motion. They found that there was a strong association between their spinal extension measurements and the Schöber test (see Section 3.11).

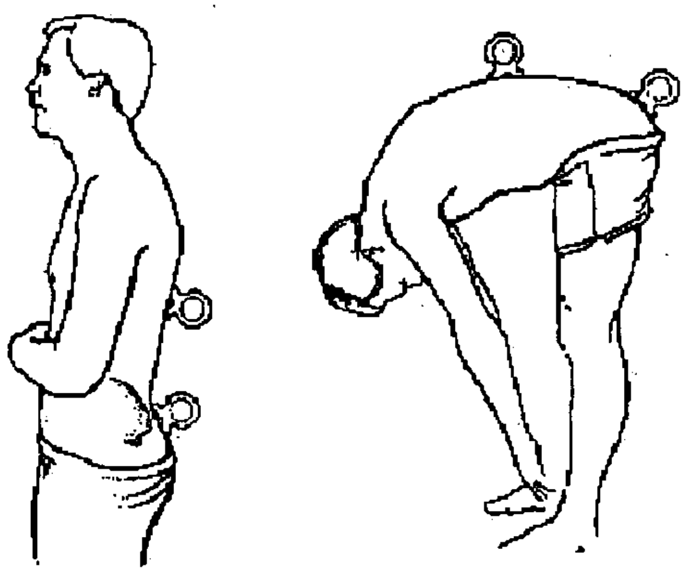

Figure 3-9 - Measuring the Spinal Contour Using an Inclinometer[1]

Tillotson and Burton [69] used an inclinometer to measure flexed and extended postures to compare with flexicurve measurements. In this study, measurements were taken with the inclinometer over the T12 spinous process and over the sacral crest at the S2 level in both the flexed and extended postures. They found that inclinometer measurements are not interchangeable with flexicurve measurements.

A full spine measurement would clearly take a sizable amount of time due to the time required for palpitation of the vertebrae and the time required

[1] Edmund M. Kosmahk. 2000. Measure Total Flexion. Retrieved March 18, 2009, from http://academic.uofs.edu/faculty/kosmahle1/courses/pt351/lect351/waddell2.htm

for each vertebral measurement. The total time can be reduced by reducing the dataset, for example by reducing the number of measured vertebrae, possibly only measuring every other vertebra or only measuring key vertebra and then interpolating the remaining vertebrae. The longer the measurement takes, the more fatigued the muscles become and that will alter the measurement results.

3.9 Barrett-Connor blocks

The Barrett-Connor blocks method is a technique which uses 1.7 cm high blocks which are placed on top of each other under the subject's occiput until the head is in a neutral position, with the subject lying supine on a radiology table (see Figure 3-10).

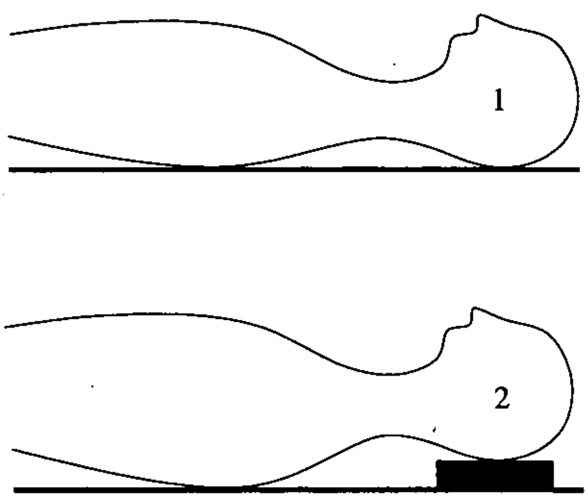

Figure 3-10 - Barrett-Connor Blocks Method
Subject 1 has normal kyphotic posture
Subject 2 has a hyperkyphotic spine

If the subject requires one or more blocks placed under their head to achieve a neutral head position then by Barrett-Connor's definition, they have a hyperkyphotic posture. The number of blocks needed under the subject's head defines the level of hyperkyphosis. This method only seems to have been used in studies involving Barrett-Connor but large studies of 1353 subjects [28] and 1578 subjects [29] have been carried out. This technique is very quick and simple however the results only confirm the presence or lack of presence of hyperkyphosis. It is also performed with the spine unloaded as the subject is in the supine position.

3.10 Matthiass (posture) test

This technique tests the functional behaviour of the spine. The test consists of two measurements taken usually 30 seconds apart. The subject stands with their arms outstretched in front of them and to exaggerate the measurements the subject can hold weights in their hands. The test looks for differences in the spinal curvature which will show which spinal segments the subject is having difficulty in stabilizing. The differences in spinal curvature occur due to the supporting muscles growing tired. Through therapy these muscles can be strengthened and this test can monitor the effectiveness of the therapy.

3.11 Schöber test

The Schöber test measures the degree of lumbar forward flexion as the subject bends over as though touching their toes. In this test a mark is made at the level of the posterior iliac spine on the vertebral column, i.e. approximately at the level of L5. The examiner then places one finger 5cm below this mark and another finger at about 10cm above this mark. The subject is then instructed to touch their toes. If the increase in distance between the two fingers on the subjects spine is less than 5cm then this is indicative of a limitation of lumbar flexion [77]. This test allows serial measurements for subjects with progressive disease to be undertaken.

3.12 Digitizers

Several studies have looked at digitizing radiographic images and then analysing the electronic versions using various computer software packages. Goh *et al* [25] used digitized radiographs in order to find a mean radius of curvature, Chen and Lee [76] used them in order to compare a skin surface marking technique with radiographic techniques.

Vialle *et al* [3] used numerous techniques on digitized radiographs to analyse sagittal spinal alignment and the balance of the spine. Digitizing is not just limited to radiographs, Räty *et al* [78] digitized flexicurve tracings to look at sagittal mobility and obtain spinal curve tangents. Tillotson and Burton [69] also used digitized flexicurves to calculate spinal curve tangents and measure the angles of the tangents to the vertical.

3.13 Conclusions

From the advantages and disadvantages given in this chapter the SpinalMouse® has been chosen for the experiments to measure the changes in the spine caused by standing on non-horizontal surfaces and wearing heeled shoes. The reasons for choosing the SpinalMouse® over the other methods are due to it being non-radiological, accurate, digital and it does not require a specialist operator. This allows the measurement of each person many times without the risk of exposing them to X-rays and does not require the results to be digitized. The device itself does not appear to have any problems although the software does have its flaws (see Section 5.3.1). However, these software flaws have been overcome through the writing of specific software for this research (see Section 5.3). Finally, the SpinalMouse® provides a very quick measurement method which is critical considering that the spinal and leg muscles will become fatigued when subjects are standing on the steeper gradients.

Chapter 4 - Spinal Analysis Techniques

Spinal analysis techniques take the raw data (radiograph, MRI image, spinal contour) and provide data which can be used for the diagnosis of spinal disorders, determining the course of treatment for a spinal disorder and monitoring the effects of a treatment or an environment that the subject is in.

The choice of analysis method is often determined by the measurement technique used. Some spinal analysis techniques can be very specific to the method of measurement. Other analysis techniques can be used on many measurement methods. Those requiring a spinal curve can use data obtained from flexicurve, X-ray, MRI or spinal pantograph.

The ideal analysis techniques to be used in this study should enable comparison of subjects by gender, by surface inclination and by footwear in order to determine how the spinal column adapts to standing on surfaces of different gradients or standing in heeled shoes and whether there are any differences between how males and females adapt.

4.1 Cobb angle measurement

This is a technique used in the diagnosis of patients with spinal disorders such as scoliosis, kyphosis and lordosis (see Section 2.4). The Cobb angle is constructed using a radiographic image of the patient's spine and can be used in both the sagittal plane and the lateral plane.

In order to measure the Cobb angle the examiner must find the apex and the base of the curve. Starting at the centre of the curve and moving superiorly, the angle of each superior vertebral endplate to the horizontal is measured. If the angle is greater than the angle of the inferior (previous) vertebra then the superior (next) vertebra is measured. Otherwise, the inferior (previous) vertebra is used as the apex vertebra. To find the base vertebra of the curve, starting at the centre and moving inferiorly, measure the angle of each inferior vertebral endplate to the horizontal. If the angle is greater than the angle of the superior (previous) vertebra then the inferior (next) vertebra is measured. Otherwise, the superior (previous) vertebra is used as the base vertebra [58]. Once the apex and base vertebrae have been found the Cobb angle is calculated by extending the line between the apex vertebra's superior endplate until it intersects the extended line from the base vertebra's inferior endplate. The angle θ between the two lines at the intersection point is the Cobb angle (see Figure 4-1). In the diagnosis of scoliosis, the course of treatment is generally decided on from the severity of the Cobb angle in the lateral plane.

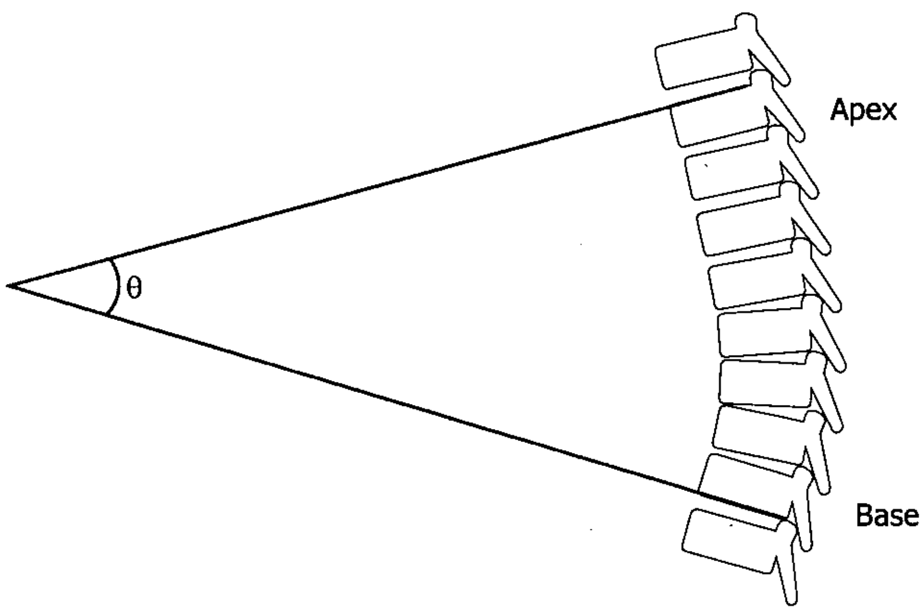

Figure 4-1 - Cobb Angle Measurement in the Sagittal Plane

The Cobb angle is still one of the most used diagnosis methods; however, it is affected by end-plate tilt (when vertebral bodies are wedge shaped) which causes misrepresentative angles. Due to end-plate tilt, Goh *et al* suggested an improved method for calculation of the Cobb angle [25]. The alternative Cobb angle uses the same procedure for choosing the curve's apex and base vertebrae. However, it differs in how the angle is measured. A line is constructed which extends through the superior endplate midpoint to the inferior endplate midpoint of the apex vertebra of the curve. A second line is constructed which extends through the superior endplate midpoint and the inferior endplate midpoint of the base vertebra of the curve. The angle θ at which those two lines intersect is the alternative Cobb angle (see Figure 4-2). The alternative Cobb angle also goes under the name of overlay angle.

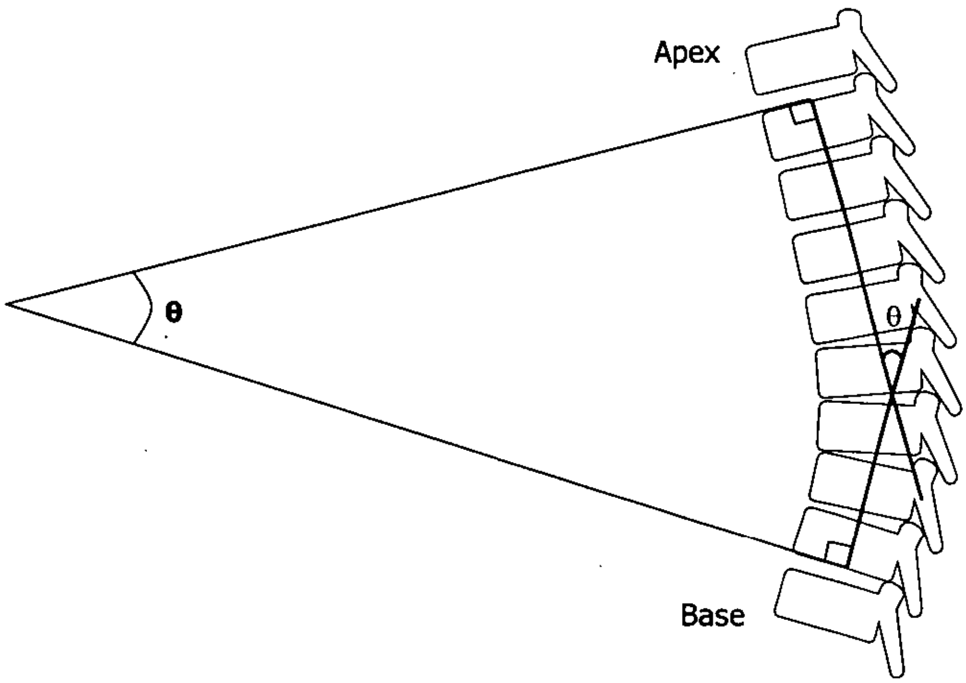

Figure 4-2 - Alternative Cobb Angle Measurement

Although construction of the Cobb angle seems rather trivial to do, it is relatively difficult when the curvature is on radiographic film as it is often difficult to determine where the endplates are and even more difficult to find the endplate extremities necessary for calculating the alternative Cobb angle.

The Cobb angle method is currently the standard technique for measuring kyphosis and scoliosis. However, another of the drawbacks of this method and the alternative method is that examiners have to use a set of compasses with a pencil to construct the angle and then a protractor to read off the angle. All of which are time consuming and error prone. The Cobb angle can only realistically be used when the examiner is able to view the vertebral bodies, such as from radiographs or MRI images. Therefore it is not a good candidate for analysing the results from the SpinalMouse® (see Section 3.3).

4.2 Index of Kyphosis (IK) and Index of Lordosis (IL)

The indices of kyphosis and lordosis, for the quantification of the thoracic and lumbar curves respectively, continue to be popular with most clinicians [27]. Both indices are calculated from curve tracings such as those from a flexicurve. Each index uses two measurements from each tracing; the maximum width of the curve and the length of the curve.

Referring to Figure 4-3, the Index of Kyphosis is the maximum width of the thoracic curve (B) divided by the length of the thoracic curve (E). The location of the transition point which defines the end of the thoracic curve and the start of the lumbar curve is defined to be where the plumb-line from C7 (the start of the measurement) intersects the curve. The formula for the Index of Kyphosis is $IK = (\frac{B}{E}) \times 100$ while the formula for the Index of Lordosis is $IL = (\frac{D}{\text{plumbline } -E}) \times 100$.

Hinman found the Index of Kyphosis protocol derived from flexicurve tracings to have a high reliability but the Index of Lordosis to be less reliable [27]. However, the Index of Kyphosis can sometimes be misleading if the patient has no lordotic curve as the thoracic length (E) will be larger and so the Index of Kyphosis will be smaller. This could cause false negatives and result in subjects with thoracic kyphosis not being diagnosed [67].

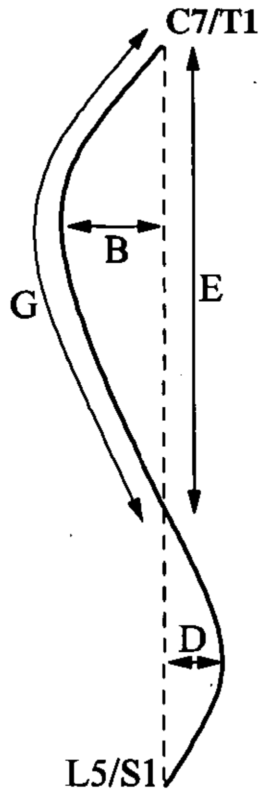

Figure 4-3 - Kyphotic Index Parameters

This index will provide a good tool to compare results either by gender or by surface or footwear. It could be a good candidate for screening and monitoring as normative values can be determined for the erect posture and it is safe for multiple measurements. However, determination of the transition point between thoracic and lumbar spines may prove difficult should the plumb line not intersect the contour which is very likely when subjects are leaning forward.

4.3 Range of Motion (RoM)

The range of motion (RoM) is an angular measurement which describes how flexible part of the spine is. There are nine measures of range of motion. These are formed from all permutations of the three types of spinal part and the three different measurement ranges

Spinal Parts

- Segmental — refers to the range of motion of a vertebral pair. e.g. T1/2 or T12/L1
- Sectional — refers to the range of motion of a spinal section; either cervical, thoracic or lumbar
- Global — refers to the overall range of motion of the spine

Measurement Ranges

- Upright-Flexion
- Upright-Extension
- Extension-Flexion

The different measurement ranges refer to how the range is calculated. Upright-Flexion ranges subtract the upright angle from the flexion angle. Upright-Extension ranges subtract the upright angle from the extension angle and Extension-Flexion ranges subtract the extension angle from the flexion angle. The angle is calculated as the angle between the tangents at the points on the curve where the vertebrae which are at the ends of the spinal part are deemed to be. For example, if trying to find a segmental extension-flexion range of motion for T1/2 an examiner would find the positions of the centres of the T1 and T2 vertebrae on the extension curve. Then the examiner would draw tangents to the curve at those two points on the extension curve. The angle at which those two tangents intersect is the extension segmental angle. This is repeated on the flexion curve to get the flexion segmental angle. The subtraction of the extension segmental angle from the flexion segmental angle gives the segmental extension-flexion range of motion for the T1/2 segment. If trying to find the thoracic section extension-flexion range of motion then the tangents for the T1 and T12 vertebrae would be used.

The range of motion is a useful technique for monitoring treatment or physiotherapeutic methods as it can test whether the range of motion is increasing as time progresses or treatments takes effect. Although this is a good comparison based approach, given that it can be used to compare inter-subject and intra-subject; it is not very useful for determining the effect of non-horizontal surfaces or wearing heeled footwear on the spine, as this investigation is observing the changes in static spinal configuration rather than the changes in the range of motion.

4.4 Angles of Curvature

The shape of the curvatures of the spine can be reduced so as to be represented as angles. The angle of curvature is often compared to the Cobb angle; however, the idea behind this analysis technique is to base the curvature of a section of the spine on an arc of a circle. Each curve of the spine; cervical, thoracic or lumbar, would be based upon an arc of a different circle and in some studies they have focused upon a subsection or an extension of a spinal curve for instance T4–T9 [24] or L1-S2 [68].

In order to obtain the curvature angle, two pieces of data must be available from each measurement; the absolute distance between the top and bottom of the arc, the arc's chord, and the maximum perpendicular distance between the chord and the arc, the chords height/rise. These can be obtained from spinal contour tracings such as those from a flexicurve measurement, or from devices specifically designed to provide these two pieces of data, such as the arcometer. Using these two pieces of data, the angle which subtends the arc and the radius of the circle which has that arc can be determined using trigonometry.

Hart and Rose [68] used a method described by Shoun to calculate the angle (β) of the shape of the lumbar spine between L1 and S2. They used a flexicurve to gather the spinal contours.

The Shoun method uses the following equation to calculate the angle

$$\beta = 4\arctan\left(\frac{2h}{l}\right)$$

where l is the spinal curve's chord length and h is the chord's height/rise (see Figure 4-4).

The method used to calculate the angle (β) of the shape of kyphosis of the thoracic spine between T1 and T12 described by D'Osualdo *et al* in their study [24] uses the equation[1]

$$\beta = 2\arcsin\left(\frac{4hl}{4h^2+l^2}\right)$$

where l is the spinal curve's chord length and h is the chord's height/rise (see Figure 4-4). Although Hart and Rose and D'Osualdo *et al* used different formulas to calculate the angle it is merely because the formulas were derived differently.

To demonstrate how D'Osualdo *et al* derived the formula for the radius of the circle or the angle which subtends the arc, let: r be the radius of the circle, l be the length of the chord, that is the shortest distance between the two ends of the arc, h be the height/rise of the chord-section, that is the greatest absolute perpendicular distance between the chord and the arc, θ be the angle which subtends the arc and d the shortest distance between the centre of the circle and the chord, which will bisect the chord at a right angle (see Figure 4-4). Thus, $d = r - h$. The only measurements that can be obtained from the various curve acquisition methods are l and h.

[1] For consistency the notations used in the diagram and subsequent formulas have been altered from those used by the original authors.

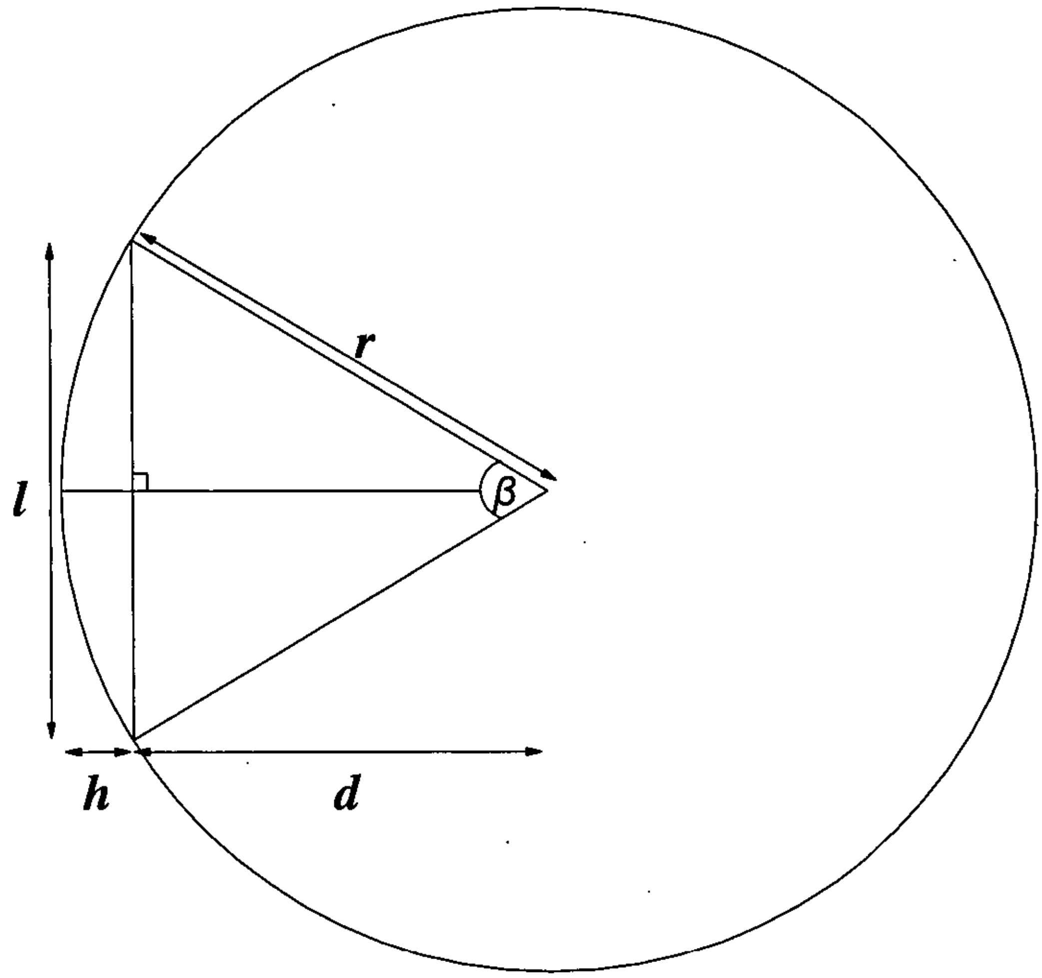

Figure 4-4 - Method Described by Shoun and D'Osualdo *et al*

Using Pythagoras,

$$r^2 = d^2 + \left(\frac{l}{2}\right)^2$$

$$r^2 = (r - h)^2 + \left(\frac{l}{2}\right)^2$$

$$r^2 = r^2 + h^2 - 2rh + \left(\frac{l}{2}\right)^2$$

$$2rh = h^2 + \left(\frac{l}{2}\right)^2$$

$$r = \frac{h^2 + (\frac{l}{2})^2}{2h}$$

Which gives

$$r = \frac{4h^2+l^2}{8h} \qquad \text{[Eq 4-1]}$$

Then using the same triangle,

$$\sin\left(\frac{\beta}{2}\right) = \frac{\left(\frac{l}{2}\right)}{r}$$

$$\sin\left(\frac{\beta}{2}\right) = \frac{l}{2r}$$

$$\frac{\beta}{2} = \arcsin\left(\frac{l}{2r}\right)$$

$$\beta = 2\arcsin\left(\frac{l}{2r}\right) \qquad \text{[Eq 4-2]}$$

Substituting r from [Eq 4-1] into [Eq 4-2] gives

$$\beta = 2\arcsin\left(\frac{l}{2\left(\frac{4h^2+l^2}{8h}\right)}\right)$$

Which, when simplified gives

$$\beta = 2\arcsin\left(\frac{4hl}{4h^2+l^2}\right) \qquad \text{[Eq 4-3]}$$

A small subtending angle implies that a person has little curvature and a large subtending angle suggests that a person has a severe curvature. Essentially, β is proportional to chord-rise (h) and inversely proportional to chord length (l).

Equation [Eq 4-3] has been derived correctly from [Eq 4-2]; however the formula quoted by D'Osualdo *et al* [24] to describe how the arcometer can be used to calculate the angles of curvatures is not correct. The quoted formula was

$$\text{angle of curvature} \quad = \arcsin\left(\frac{\text{chordlength}}{\text{radius}}\right)$$

which, when converted to the above notation is

$$\beta = \arcsin\left(\frac{l}{r}\right)$$

The authors probably arrived at [Eq 4-2] and then incorrectly cancelled out the twos. If the wrong formula was used by D'Osualdo *et al* in calculating their results then it is possible that the comparison of the arcometer to radiographic techniques was also incorrect. After further research it was found that this mistake had been discovered. A paper by Leroux *et al* [31] mentions that "the reproduction of calculations was not accurate" suggesting that the correct calculations were used in the experiment.

A major flaw of the method of Shoun and D'Osualdo *et al* is to assume that each spinal curve is symmetrical about its chord-rise, i.e. that the maximal arc rise bisects the arc chord. However, Gray [2] stated that the lumbar spine is more curved in the lower three vertebrae (L3-L5) than the first two (L1-L2).

Leroux *et al* [31] suggested an improved method for analysing the curvature of the spine which was to represent the kyphotic curve as the arcs of two circles. Their proposed method splits the curve into two arcs, using the maximum arc rise as the break point (see Figure 4-5). By using this method a spinal curve can be represented more accurately using the sum of the two angles. The approach taken by Leroux *et al* also appears to correlate better with radiographic measurement, although, this could be due to them using videographic techniques rather than the arcometer. The differences between means for the thoracic spine between skin surface measurement derived angle of curvature and radiographic derived Cobb angle in both studies was the same, however, the study by Leroux *et al* showed a lower standard deviation.

To demonstrate how the formula for the subtending angle of each arc of each circle is derived by Leroux's method, let: r_i be the radius of the circle which the arc is a part of, l_i be the length of spinal curve chord between the two radii that subtend the arc, h be the height/rise of the spinal curve chord, that is the greatest absolute distance perpendicularly between the chord and the spinal curve, γ_i be the angle which subtends the arc and d_i the shortest distance between the centre of the arc's circle and the chord. Thus, $d_i = r_i - h$. A right angled triangle is created with d_i, l_i and r_i with l_i being opposite γ_i and r_i as the hypotenuse (see Figure 4-5).

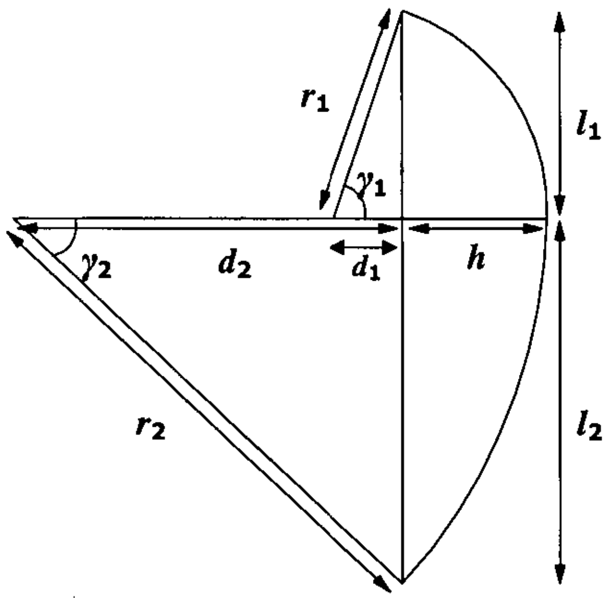

Figure 4-5 – Method Proposed by Leroux *et al* for Calculating a More Representative Angle of Curvature[1]

The only measurements that can be acquired from the various curve acquisition methods are l_i and h .

So

$$l_i = r_i \sin \gamma_i$$

$$r_i = \frac{l_i}{\sin \gamma_i} \qquad \text{[Eq 4-4]}$$

[1] For consistency the notations used in the diagram and subsequent formulas have been altered from those used by the original authors.

Then, using the same triangle,

$$d_i = r_i \cos \gamma_i$$

Substitute $d_i = r_i - h$

$$r_i - h = r_i \cos \gamma_i$$

$$h = r_i - r_i \cos \gamma_i$$

$$r_i = \frac{h}{1 - \cos \gamma_i} \qquad \text{[Eq 4-5]}$$

Substitute [Eq 4-4] into [Eq 4-5]

$$\frac{l_i}{\sin \gamma_i} = \frac{h}{1 - \cos \gamma_i}$$

$$\frac{l_i}{h} = \frac{\sin \gamma_i}{1 - \cos \gamma_i}$$

Then, using the trigonometric identity $\cot\left(\frac{\theta}{2}\right) = \frac{\sin \theta}{(1 - \cos \theta)}$

gives

$$\frac{l_i}{h} = \cot\left(\frac{\gamma_i}{2}\right)$$

Using $\cot \theta = \tan(90 - \theta)$ gives

$$\frac{l_i}{h} = \tan\left(90 - \left(\frac{\gamma_i}{2}\right)\right)$$

$$\frac{l_i}{h} = \tan\left(\frac{180 - \gamma_i}{2}\right)$$

$$\left(\frac{180 - \gamma_i}{2}\right) = \arctan\left(\frac{l_i}{h}\right)$$

$$180 - \gamma_i = 2 \arctan\left(\frac{l_i}{h}\right)$$

$$\gamma_i = 180 - 2 \arctan\left(\frac{l_i}{h}\right)$$

as quoted by Leroux *et al.* However, this can be simplified to

$$\gamma_i = 2 \arctan\left(\frac{h}{l_i}\right) \qquad \text{[Eq 4-6]}$$

4.5 Thoracolumbar Offset

The thoracolumbar offset describes the angle (Φ), in the sagittal plane, that the thoracolumbar spine makes with the vertical (see Figure 4-6). Changes in the thoracolumbar spine cause a shift in the subject's centre of mass. When walking, subjects lean forward slightly to assist in forward momentum. However when walking downhill the forward leaning can cause the sensation of falling forwards so the thoracolumbar spine is either maintained in the neutral posture or tilted slightly backwards. However, when standing, this could be different. Postural adaptations are task specific and as such, studies need to be performed on a per task basis.

The offset can be calculated from radiographs and skin-surface contours where the orientation of the spine is known. The offset can also be calculated using the SpinalMouse® and skin-marker techniques. The angle is calculated by constructing a line from the start to the end of the vertebral range to be measured and reading off the angle that this line makes with the vertical. With digitized results this process can be performed much faster and more accurately compared to measuring the angles using a protractor.

Vialle *et al* [3] measured the T1 and the T9 thoracolumbar offset of 300 asymptomatic subjects using the line from the selected vertebra to the centre of the bicoxofemoral axis. Comparisons between genders showed that the male and female subjects showed no significant differences between T9 thoracolumbar offsets but that the female subjects had a significantly higher T1 thoracolumbar offset than the male subjects ($p < 0.05$).

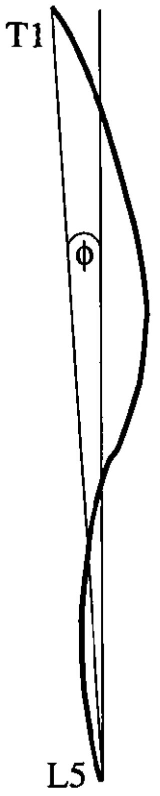

Figure 4-6 – T1-L5 Thoracolumbar Offset

Leroux *et al* [50] investigated the walking trunk inclination in the sagittal plane of eight subjects with spinal cord injuries (SCI) against eight healthy matched subjects. They measured the subjects on a treadmill, which could be inclined and declined up to 5.7° (10%), using skin markers and high resolution cameras. The trunk segment was defined to be from the C7 vertebra to the L3 vertebra. Subjects completed two measurement phases, the first measurement phase was static walking posture the second was active walking. They concluded that in static walking posture there was no change in trunk inclination caused by the angle of the treadmill in either of the groups. However, in active walking, both groups increased their trunk inclination as the treadmill inclined, also the healthy subjects decreased their trunk inclination as the treadmill surface declined. Finally, the SCI subjects were found to react less to the surface they were walking on, thus increasing the risk of losing balance.

The thoracolumbar offset angle clearly does not give any information about the curvatures of the spine, nor can they be inferred. Using just this analysis technique there would be nothing to distinguish between a subject with accentuated spinal curves (e.g. hyperkyphosis) and a subject with flat-back syndrome. However, it does give an indication of the adaptation of the spinal column caused by the environment/task that the other analysis methods do not; namely, how the trunk is orientated.

4.6 Vertebral axis angle measurements

The vertebral axis angle is another technique used to quantify the sagittal curves of the human spine. The vertebral axis angle is constructed using a radiographic image of the patient's spine.

The vertebral axis angle is calculated by constructing a curve through the centres of the vertebral bodies of a section of the spine. A chord is constructed from the centre of the first vertebra in the range to the centre of the last vertebra in the range and its length is recorded (l). Then, the maximum chord height/rise is calculated and recorded (h) (see Figure 4-7). To calculate the angle, the same formula that is used to calculate the Shoun angle is used (see Section 4.4). The vertebral axis technique and the Shoun method are compared by Hart and Rose [68] to a Cobb angle type measurement using the inferior endplates of lumbar vertebra. They found that the vertebral axis angle correlated poorly with the Shoun method, but that both methods correlated well with the Cobb angle type measurement. However, the three correlations found in this study all go against those findings by Shoun. This could be because Hart and Rose only carried out eight radiographic measurements.

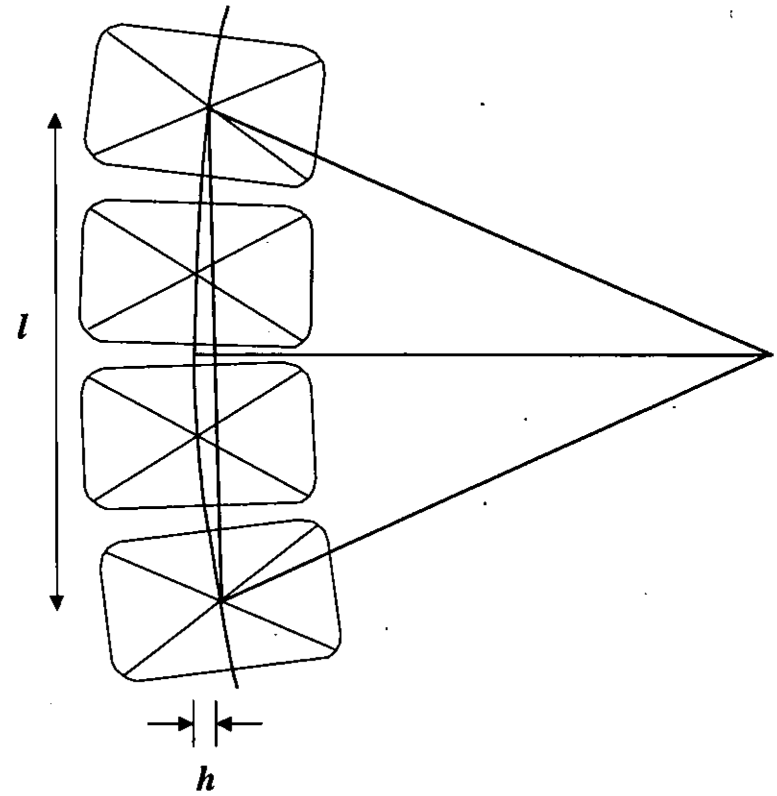

Figure 4-7 - Vertebral Axis Angle

The vertebral axis angle method suffers from the same problems as the Cobb angle in that the boundaries of the vertebral bodies need to be defined and this is generally performed by hand, and so there is scope for significant differences both inter-examiner and intra-examiner.

4.7 Elliptical models of sections of the spine

There have been numerous reports written involving Harrison, Harrison and Janik [12, 15, 18, 26, 79, 80] which have suggested that arcs of ellipses as well as arcs of circles can be used to model the sagittal curvature of certain sections of the spine. They have suggested that sagittal lumbar curvature can be approximated to the arc of an ellipse [79, 80] (see Figure 4-8), that circle and ellipse arcs can be used to model thoracic kyphosis [18, 26] and that the sagittal cervical spine can be modelled using the arc of an ellipse or circle [12, 15].

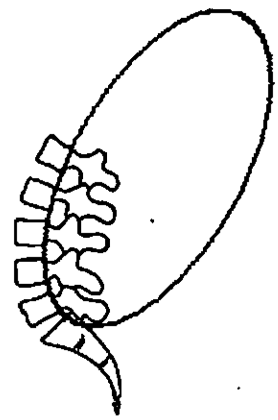

Figure 4-8 - Elliptical Model of the Lumbar Spine

In each of their reports they used radiographic images of patients on which they marked the inferior-posterior and superior-posterior positions of each vertebral body in the range. The arc of an ellipse/circle was then fit, using least squares fitting, to these points so that the arc had less than 1mm least squares error per point.

In their paper published in 1996 [12], they showed that the cervical spine from C2 to C7 can be modelled on a circle. These results were based upon the X-rays of 400 participants which were measured by hand.

In their paper published in 1998 [80] they showed that the lumbar spine, specifically from the inferior of T12 to the superior of S1, could be modelled in a least squares method to that of an ellipse with a minor to major axis ratio of 0.4 and an arc quadrant of 85°. This elliptical lumbar model was based upon X-rays of 50 normal lumbar spines which were digitized and then had the computer test for elliptical/circle fitting using an iterative process. They carried out a follow up study [79] which was designed to test whether this elliptical model could discriminate between those with low back pain and those without. The fit of the elliptical model to the lumbar spine conforms to other research which has found that there is more curvature between the L3-L5 vertebrae than there is between L1 and L2 [2, 3].

In papers published in 2002 [18] and 2003 [26] they modelled the thoracic spine on ellipse arcs. The ellipses used had minor to major axes ratios of 0.7. The thoracic section measured was from T1 to T12. Again, X-ray images that had been digitized were used.

In 2004 they published another paper [15] which modelled the cervical spine using the same techniques used to model the lumbar and thoracic spines. This different approach found an ellipse as a good model. When they included T1 in the range it was found that a circle was a closer match.

The papers also provided the ideal segmental angles between all vertebrae involved and the ideal global angle between the tangents to the curve of the highest and lowest vertebrae involved.

The Cartesian equation of an ellipse, which has its major axis parallel to the x-axis and its minor axis parallel to the y-axis, is $\frac{(x-t)^2}{a^2}+\frac{(y-s)^2}{b^2}=1$ where s and t are the x and y co-ordinates, respectively, of the centre of the ellipse, a is the length of the semi-major axis and b is the length of the semi-minor axis. Although an exact elliptical formula cannot be found, as everyone has a different spine length, the ratio of the minor to major axes (b/a) of an ellipse will give a set of mathematically similar ellipses that will match a given ideal spinal curvature. For example, if the minor to major axes ratio is 0.7 then the set of ellipses would be:

$$\frac{(x-t)^2}{p^2}+\frac{(y-s)^2}{(0.7p)^2}=1 \text{ where } p \in \mathrm{R}$$

For an ellipse rotated by θ about the origin and then translated by t in the x direction and s in the y direction the Cartesian equation is

$$\frac{(x\cos\theta-y\sin\theta-t)^2}{a^2}+\frac{(x\sin\theta+y\cos\theta-s)^2}{b^2}=1$$

Elliptical modelling could be used to describe the curves of the spine; however, the ability to compare curves using this method is not known.

4.8 Tangential Radiologic Assessment of Lumbar Lordosis (TRALL) angle

The TRALL angle analysis technique is used for analysing the sagittal lumbar curve from radiographic images [32, 81].

The TRALL angle is constructed as follows: an arc is drawn along the posterior vertebral bodies from the superior-posterior corner of the L1 vertebra (point A) to the inferior-posterior corner of the S2 vertebra (point B). A line is then constructed between point A and point B. Another point (point C) is marked at the point on the arc that is furthest from the line between points A and B. Two lines are then constructed between points C and A (line CA) and points B and C (line BC). The angle between the extension of line BC and the line CA is the TRALL angle, (see Figure 4-9).

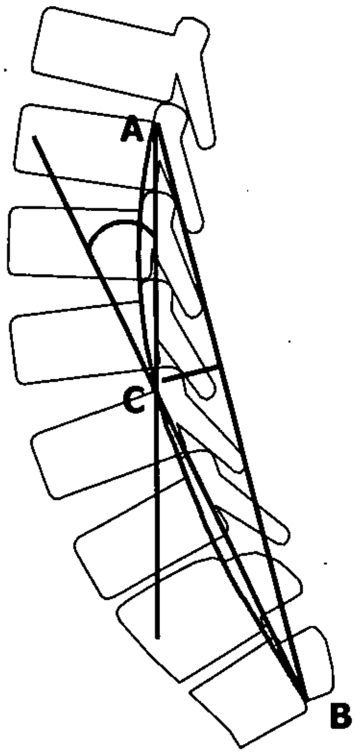

Figure 4-9 - TRALL Angle

Chernukha *et al* [32] proposed this curvature analysis technique as a more reliable method than the Cobb angle for measuring lumbar lordosis. The Cobb angle has produced, in some studies, quite large ranges of normal values which would, as such, have created quite a large number of false negatives (people that had a disorder but it was not detected). The Cobb angle also has a relatively large standard deviation associated with it. In the tests, it became apparent that the TRALL method showed less variability in lumbar lordosis measurements of those without vertebral and pelvic abnormalities. The reason that the Cobb angle produces a larger range of normal lordosis measurements is because it is difficult, on radiographs, to determine the angle of the endplate, due to the endplate not being a flat surface. Therefore the examiner of the radiograph could make any one of a number of decisions about what the angle the endplate is. The TRALL angle does not suffer from this as it uses the posterior vertebral body curve to construct the curve, which is, apparently, a stable structural unit. Chernukha *et al* indicated that there is no connection between the Cobb angle and the TRALL angle in terms of converting one to the other unlike other analytical methods; mainly because of the variability of the Cobb angle. Chernukha *et al* also showed that the TRALL angle was as reproducible as the Cobb angle.

A potential problem with the TRALL angle could be that most of the sacral vertebral boundaries are not easily identifiable from radiographs (see Figure 4-10) due to the sacral vertebrae being fused and because the ilia absorb some of the X-rays. These problems could be overcome by using MRI.

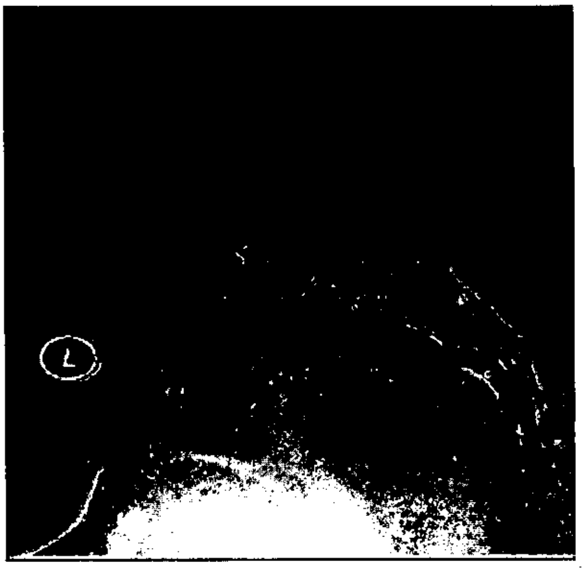

Figure 4-10 - Lateral Sacrum Radiograph[1]

The TRALL angle could be used to analyse the shape of the lumbar spine. As there have been no known studies, to date, which have used the same methodology as the TRALL angle to quantify the thoracic curve, a feasibility study could be conducted to ascertain whether it could be used. However, the TRALL angle does require a measurement technique which outputs the locations and boundaries of the vertebrae such as radiographs or MRI images.

[1] Nicholas Joseph Jr. 2006. Diagnostic Criteria for Imaging the AP and Lateral Views of the Lumbosacral Spine. Retrieved March 18, 2009 from http://www.ceessentials.net/article23.html

4.9 Bézier curves

Bézier curves are curves of degree n which can be defined using $n-1$ control points $\{P_0, \ldots, P_n\}$ and the expression

$$P(t) = \sum_{i=0}^{n} B_i^n(t) P_i \text{ for } 0 \leq t \leq 1$$

where

$$B_i^n(t) = C_n^i t^i (1-t)^{n-i} \text{ and } C_n^i = \frac{n!}{i!(n-i)!}$$

So a cubic Bézier curve would be

$$P(t) = \sum_{i=0}^{3} B_i^3(t) P_i \text{ for } 0 \leq t \leq 1$$

which when expanded and simplified is

$$P(t) = (1-t)^3 P_0 + 3t(1-t)^2 P_1 + 3t^2(1-t) P_2 + t^3 P_3 \text{ for } 0 \leq t \leq 1$$

The values of t depend on the resolution of the curve required.

Bézier curves can be used to quantify the shape of individual spinal curves or the shape of the entire thoracolumbar spine in both sagittal and lateral planes. Bézier curves are useful in computer applications as they take up very little storage room and are easily scalable. However, although they are easy to construct, the only way to calculate the control points to construct a Bézier curve from a set of curve co-ordinates is to estimate the positions of the control points and then iteratively alter the estimated control points until the Bézier approximately runs through the set of curve co-ordinates. Although Bézier curves could potentially be used to describe spinal contours and with determined levels of error they could be used to describe a set of ideal spinal curves, their application in comparing contours is unknown.

4.10 Conclusions

Although the Cobb angle is considered to be the 'gold' standard by many, this is because they are generating Cobb angles from X-rays. As the SpinalMouse® has been chosen to measure the subjects' spinal contours rather than X-rays (see Chapter 3), in order to not expose the subjects to harmful radiation, the Cobb angle is not a valid choice of analysis technique. By performing a skin-surface measurement the boundaries and locations of the vertebral bodies can not be obtained and subsequently the end-plates are not available from which to draw the Cobb angle. Although the tangents of the contour can be found and the perpendiculars to the tangents extended, resulting in a Cobb-like angle, there are better methods available which are more appropriate for skin-surface measurements. The Cobb angle has its drawbacks; different analysts generally measure the angle differently due to the unevenness of the vertebral end-plates. The choice of the SpinalMouse® as the measurement technique rather than a technique which outputs an image of the vertebrae also discounts the vertebral axis angle and the TRALL angle as being viable analysis techniques. Although elliptical modelling could be used with a skin-surface contour rather than a radiographic image it would be difficult to compare the differences between genders, surfaces and footwear using the resulting elliptical equations. This problem is shared with attempting to model the curves on Bézier curves. The indices of kyphosis and lordosis would be useful for comparing the spines of males and females on horizontal ground and possibly when wearing the various footwear, however if the subject were to lean such that the plumb-line did not intersect the spinal contour then this method is also not suitable.

In order to determine the effects of standing on non-horizontal surfaces and in various footwear the Shoun and Leroux techniques were chosen to describe the curvatures and the thoracolumbar offset is chosen to obtain the orientation of the trunk. Together they provide a more complete description of how the spinal column adapts to the environment/task that it is being subjected to. The steps involved in calculating the Shoun angle and the Leroux angle are similar, although the Shoun angle is computationally simpler, however analysing changes in curvature using both methods provides a more thorough analysis and may highlight postural changes which would have been missed if using only a single method.

Chapter 5 - Experiments to Measure Sagittal Spinal Contour

In order to determine how people maintain balance, when standing on different surface gradients and when wearing different footwear, an experiment was devised to measure the contour of the spine while they were standing on various surfaces and while they were wearing various footwear. This chapter describes this experiment and the software produced to process the data.

5.1 Sample Population

39 volunteers from Loughborough University (23-58 years, mean 30.2 years) had their sagittal spinal contour measured from T1 to L5 while standing on a surface which could be inclined and declined. There were 20 males (23-36 years, mean 27.0 years) and 19 females (24-58 years, mean 33.7 years). Table 5-1 outlines the sample population's demographic characteristics.

Table 5-1 - Sample Population Demographics

	Height (cm)		Weight (kg)		Age	
	Male	Female	Male	Female	Male	Female
Maximum	190.5	171.3	112.0	86.7	36	58
Minimum	169.0	156.0	55.5	47.3	23	24
Average	178.3	164.3	74.3	52.0	27.0	33.7
SD	5.6	4.3	12.8	11.2	3.4	10.9

The 39 subjects that took part in the experiment were all asymptomatic volunteers from Loughborough University. Prerequisites were that they were not pregnant, had not got any spinal disorders, were not suffering at the time of the experiment from an episode of back pain and were between 18 and 60 years of age. The experiment was approved by the Loughborough University Ethical Advisory Committee and all subjects read and signed documentation stating that they understood what was going to happen during the experiment and that they were willing for their data to be used anonymously for the purposes of this research.

5.2 Methodology

A wooden platform was designed, consisting of two flat wooden boards hinged together (see Figure 5-1) so that the angle between the boards (θ) could be altered by changing the board (b) which separated them. The changeable boards are kept in place by stocks attached to the hinged boards. For the rest of this thesis, positive values of θ indicate that the subject was standing facing uphill, whereas negative values of θ mean that the subject was standing facing downhill. By changing board b the surface gradient is adjustable within the −30° to 30° range in 5° increments; allowing each subject to be measured on 13 different surface inclinations. For the experiment the platform was placed on horizontal ground. Subjects' spinal contour was recorded twice at each surface inclination using the SpinalMouse®, both within one minute of the subject standing on the platform. The first measurement was taken as soon as the subject stated that they had adopted a comfortable position and that they were secure in standing on the platform at that angle. The second measurement was taken 30 seconds after the first measurement started to ensure that there was consistency between the measurement intervals. Between the measurements at different gradients, subjects were able to sit down and rest while the data was recorded.

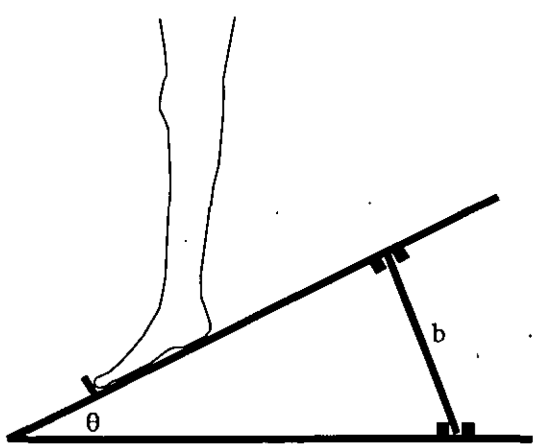

Figure 5-1 - The Platform. The angle θ is altered by changing board b

Subjects wore light, thin clothing so that more accurate readings could be acquired from the SpinalMouse®. Subjects were asked to stand comfortably, facing forwards with their heads level and with the toes of both of their feet against a footrest incorporated into the inclined surface. For this experiment the 'upright' in the 'standing in sagittal plane' mode of the SpinalMouse® software was used. Measurements were made paravertebrally starting at C7 and going down to S3. The C7 vertebra was identified by its prominence on the skin surface which was visible on all subjects. The S3 vertebra was identified as being at the superior point of the anal fold as per the SpinalMouse® instructions. Although the SpinalMouse® measurement is performed from C7 to S3, measurement data is given for the T1 to L5 range and the sacrum angle.

Additionally, females were asked to repeat the experiment wearing two different pairs of heeled shoes, to as high a surface angle as they could manage. All females wore the same two pairs of heeled shoes for the experiment; both pairs of shoes were UK size 8 shoes, with all subjects able to stand in them comfortably. One pair had small heels while the other pair had high heels. The heels of the smaller heeled shoes measured 50 mm while the heels of the higher heeled shoes measured 82 mm. In angular terms the smaller heeled shoes made an angle of 13° with the horizontal while the higher heeled shoes made an angle of 22° with the horizontal. This angular measurement incorporates the whole shoe rather than just the arch angle which is much steeper.

5.3 Software

The software that is provided with the SpinalMouse® allows intra-subject comparison of two upright postures at a time. The data presented to the user consists of intervertebral angles (see Figure 3-4) from T1/T2 to L5/S1, the sacrum angle, the spinal length and the thoracic and lumbar curvatures. These data can be displayed on screen or be exported as an Excel® file. The calculation of the thoracic and lumbar curves is through the summation of intervertebral angles of each curve.

5.3.1 SpinalMouse® Software Drawbacks

There are drawbacks to the SpinalMouse® software, apart from failing to meet many HCI principles, leaving users potentially confused, the software also has many limitations, a few of them used to protect the software algorithms from being reverse engineered. The major design flaws and limitations of the software are listed below:

- All spine measurements have to be taken between C7 and S3, there is not a method to measure just a subsection of the spine e.g. thoracic section and it is not possible to measure the cervical section of the spine
- To obtain a set of data so that ranges of motion can be calculated, measurements in flexion, extension and upright positions have to be carried out one after the other without a break
- Lack of consistency between certain features which should use the same user interaction style
- The English version of the software is a direct translation from the German version and as such the true meaning of some options can be misunderstood. For example when deleting a measurement the user is asked whether they want to delete the measurement and the options given are 'continue' and 'delete'. Here, both the options given to the user suggest that the measurement will be deleted. Normally the user would have the options 'OK' and 'Cancel' (a positive and a negative response to the question).
- Free mode analysis is not exportable to Excel® like the spinal Range of Motion measurements
- Free mode only allows 22 measurement points and does not allow points to be moved or deleted

Another flaw in the SpinalMouse® package is that although the software provides mean and standard deviation measurement data (including upright, extension and flexion measurements and the derived measurements, such as upright-flexion range of motion) collected from people that have been analysed using SpinalMouse®, the developers fail to clarify the demographics of the sample population. The only information provided is the age range (18-35, 36-55 or 56-75) and the gender. It would be useful to know: the height and weight means or ranges, whether these people were all free from spinal problems and at the time of the test not suffering from any forms of back pain, their ethnicities and whether they all had a healthy BMI (see Section 2.4). The SpinalMouse® would be a good tool to use for diagnosing and researching into many spinal disorders if the software provided more information. With a higher measuring accuracy than many other methods it may prove to be a reliable method for analysing surface curvatures. The most useful information that could be provided is the co-ordinate data for the curve. Co-ordinate data must be calculated in order to display the curvature on the screen so it could be made available. Unfortunately, idiag™ (the producer) are reluctant to provide any more data as it may compromise their algorithm which calculates where the vertebrae are on the curve. With curve co-ordinate data it would be possible to use the data from the SpinalMouse® in most spinal surface curvature analysis techniques. With the information that it collects the SpinalMouse® could:

- allow comparisons of one subject's measurements to another or compare one subject over time.
- create a complete subject report with both sagittal and lateral measurements rather than just one or the other.

- calculate the tangential angle and distance along the curve between two user selected points, this is currently only available in the free mode.

5.3.2 Development of New SpinalMouse® Software

This research required development of improved software that would overcome the limitations of the SpinalMouse® software and allow results to be generated using alternative analysis techniques. The new software is written in Java™ and uses a MySQL® database for storing the spinal curve data. This new software allows comparison of as many spinal contours as wanted and displays them on screen simultaneously. It also generates data files to be used by SPSS® (SPSS Inc. USA) for the analysis of spinal inclinations and curvature angles.

The software accepts, as input, the Excel® file exported by the SpinalMouse® software. From this file it extracts the set of intervertebral angles the sacrum angle and the spinal length. The software saves these 17 intervertebral angles, sacrum angle and the spinal length in the database and links them to the subjects' attributes which the user enters. Using the set of intervertebral angles, the sacrum angle and the spinal length combined with anthropometric data from Acar and Grilli [82] the spinal contour is recreated. The anthropometric data provides the distance between adjacent vertebral inferior end-plates. Using this set of intervertebral distances a set of intervertebral ratios are calculated by dividing each intervertebral distance by the sum of the intervertebral distances. Multiplying each intervertebral ratio by the subject's spinal length (output by the SpinalMouse®) gives a collection of subject specific vertebral heights.

Vertebral orientation is calculated as the cumulative sum of intervertebral angles from the base of the spine to the vertebra. The L5 vertebra is orientated at the sacrum angle plus the L5/S1 intervertebral angle. The L4 vertebra is orientated at the L5 orientation plus the L4/L5 intervertebral angle and the L3 vertebra is orientated at the L4 orientation plus the L3/L4 intervertebral angle. Orientation angles and the sacrum angle are measured anti-clockwise from the vertical. Positive intervertebral angles are those which are in kyphosis/flexion, whereas negative intervertebral angles are those which are in lordosis/extension. The subject specific vertebral heights, combined with the corresponding orientations, are used to generate the spinal curves.

Starting from the co-ordinates (0, 0) a line segment, equal to the subject's L5 vertebral height, is drawn at the L5 orientation angle (sacrum angle plus L5/S1) from the vertical (see Figure 5-2). From the end point of this line, a second line segment, equal to the subject's L4 vertebral height, is drawn at the L4 orientation (L5 orientation plus the L4/L5 angle) from the vertical (see Figure 5-3). This is repeated up to and including the T1 vertebra. This process results in a set of co-ordinates describing the locations of the inferior end-plates of the vertebrae from C7 to L5 and therefore, the shape of the subject's spinal contour. In order to display the spinal curvature on the computer screen, all the co-ordinates are translated vertically so that the inferior C7 end-plate y co-ordinate is at -50 due to computer screens' co-ordinate systems starting with (0, 0) in the top left hand corner and so that there was a 50 pixel border around the spinal curvature. The system then finds the lowest x co-ordinate and horizontally translates all the co-ordinates so that the lowest x co-ordinate is 50 (see Figure 5-4). All spinal contours are created with the subjects facing to the left.

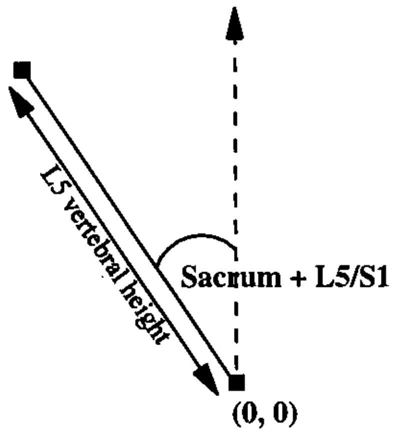

Figure 5-2 - Construction of the L5 vertebra

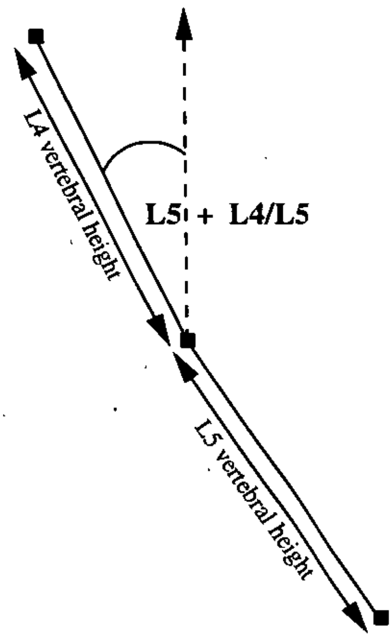

Figure 5-3 - Construction of the L4 vertebra

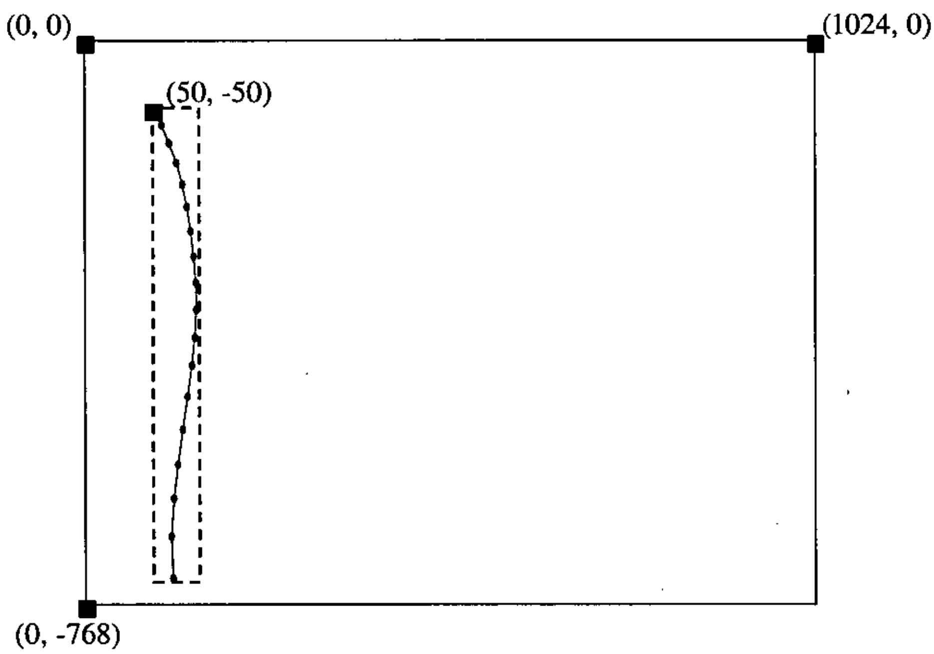

Figure 5-4 - Translating spinal curve to screen's co-ordinate system

From the spinal contour co-ordinates it is then possible to calculate the thoracolumbar offset and the angles of curvature as described by Shoun [68], D'Osualdo *et al* [24] and Leroux *et al* [31] for the different measurement ranges.

5.3.3 Calculation of Thoracolumbar Offset Angle

Using Cartesian components the C7-L5 thoracolumbar offset (ϕ) is calculated using the tangent rule and the difference in x co-ordinate (Δx) between the C7 and L5 co-ordinates for the side opposite the angle and the difference in y co-ordinate (Δy) between the C7 and L5 co-ordinates for the vertical component to calculate the angle that the thoracolumbar column makes with the vertical (see Figure 5-5). So that positive values imply forward leaning, the result is multiplied by -1.

$$\phi = -\ \arctan\left(\frac{\Delta x}{\Delta y}\right)$$

$$\phi = -\ \arctan\left(\frac{C7_x - L5_x}{C7_y - L5_y}\right)$$

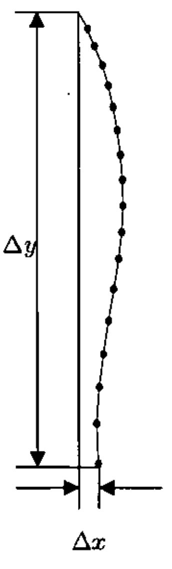

Figure 5-5 - Calculation of Spinal Offset

5.3.4 Calculation of Angles of Curvature

To calculate the angles of curvature as described by Shoun [68] and Leroux [31] requires more calculations.

Step 1: Calculate the length of the chord (l). Using the co-ordinates of the start and end vertebrae it is possible to calculate the distance between them using Pythagoras.

$$l = \sqrt{((\Delta x)^2 + (\Delta y)^2)}$$

Step 2: Calculate the equation of the chord. Using the co-ordinates of the start and end vertebrae the chord's gradient (m) is calculated as the change in y co-ordinate divided by the change in x co-ordinate

$$m = \frac{\Delta y}{\Delta x}$$

Then, using the gradient and the co-ordinates of either the start or the end vertebra in the equation $y = mx + c$ the equation of the chord can be calculated.

Step 3: Calculate the gradient (m') of a line which is perpendicular to the chord. This is calculated using

$$m' = -\frac{1}{m}$$

Step 4: For each vertebra between the start and end vertebrae find the equation of the line perpendicular to the chord which intersects the vertebra. Using m' in $y = m'x + c'$ and substituting x and y with the x and y co-ordinates of each vertebrae the set of line equations can be found.

Step 5: For each line equation generated in Step 4, find where it intersects the chord. This is calculated by solving the following equation for x

$$m'x + c' = mx + c$$

and then calculating y using the equation of the chord with the value of x.

Step 6: Determine the vertebra which is furthest away from the chord. For each line equation calculated in Step 4, find the distance between the vertebra it intersects and the intersection point on the chord using Pythagoras. The maximum distance is the arc rise (h).

For calculating the angle of curvature according to the method outlined by Shoun [68] and D'Osualdo *et al* [24]

Step 7S: Calculate the angle of curvature (β). Insert h and l into the formula

$$\beta = 2\arcsin\left(\frac{4hl}{4h^2+l^2}\right)$$

For calculating the angle of curvature according to the method outlined by Leroux [31]

Step 7L: Find the distance (l_I) between the start vertebra and the intersection point on the chord of the line perpendicular to the chord which intersects the vertebra furthest away from the chord. This is achieved using Pythagoras.

Step 8L: Calculate the angle of curvature (γ). The angle of curvature using the Leroux method is calculated as

$$\gamma = \gamma_1 + \gamma_2 \quad \text{where} \quad \gamma_i = 2\arctan\left(\frac{h}{l_i}\right)$$

as $l_2 = l - l_1$, insert h, l and l_I into the formula

$$\gamma = 2\arctan\left(\frac{h}{l_1}\right) + 2\arctan\left(\frac{h}{l-l_1}\right)$$

The two techniques for calculation of the angle of curvature can be repeated for both the thoracic and lumbar spines. The system can then output the angles of curvature in a form which can be easily uploaded into SPSS®, the software package which was used for analysis of the results.

Following, is a worked example of how the Leroux and Shoun angles are calculated. It is split up into the steps previously described. The example uses actual vertebral co-ordinates from one of the subjects. The co-ordinates for the vertebral inferior end-plates are L1: (44, -312), L2: (38, -345), L3: (35, -379), L4: (33, -416) and L5: (36, -456) (see Figure 5-6).

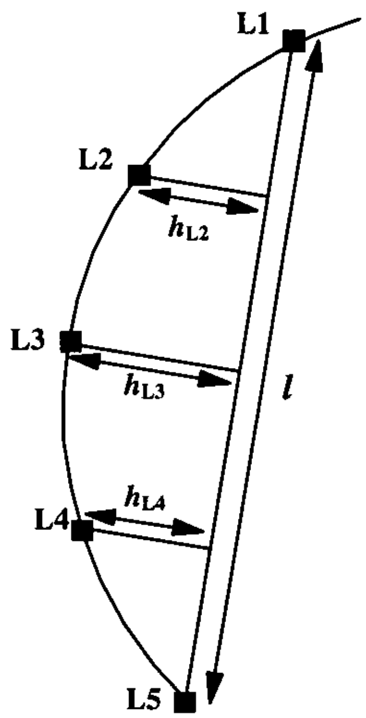

Figure 5-6 - Calculating the L1-L5 Angle of Curvature[1]

Step 1: Calculate the length of the L1-L5 chord

$$l = \sqrt{((\Delta x)^2 + (\Delta y)^2)}$$

$$l = \sqrt{((44 - 36)^2 + (-312 - (-456))^2)}$$

[1] Image represents the general theory rather than the particular instance

$$l = \sqrt{(8^2 + 144^2)}$$

$$l = \sqrt{20800} = 40\sqrt{13}$$

Step 2: Calculate the equation of the L1-L5 chord

Find the gradient of the chord (m)

$$m = \frac{\Delta y}{\Delta x}$$

$$m = \frac{(-456-(-312))}{(36-44)}$$

$$m = \frac{-144}{-8}$$

$$m = 18$$

Using one of the vertebral co-ordinates calculate c

For L5 at (36, -456)

$$y = mx + c$$

$$-456 = (18 \times 36) + c$$

$$c = -456 - 648$$

$$c = -1104$$

So the equation of the chord is $y = 18x - 1104$.

Step 3: Calculate the gradient (m') of a line which is perpendicular to the L1-L5 chord

$$m' = -\frac{1}{m}$$

$$m' = -\frac{1}{18}$$

Step 4: For each vertebra between L1 and L5 find the equation of the line perpendicular to the chord which intersects the vertebra

For L2 at (38, -345)

$$y = m'x + c'$$

$$-345 = -\tfrac{38}{18} + c'$$

$$c' = \tfrac{38}{18} - 345$$

$$c' = \frac{38 - (345 \times 18)}{18}$$

$$c' = \frac{(38 - 6210)}{18} = -\frac{6172}{18}$$

Equation of the line which is perpendicular to the L1-L5 chord and intersects L2 at (38, -345) is:

$$y = -\left(\frac{x+6172}{18}\right)$$

Similarly, the equations for the lines perpendicular to the L1-L5 chord which intersect L3 and L4 are $y = -\left(\frac{x+6787}{18}\right)$ and $y = -\left(\frac{x+7455}{18}\right)$ respectively.

Step 5: Find the points where the lines with equations $y = -\left(\frac{x+6172}{18}\right)$, $y = -\left(\frac{x+6787}{18}\right)$ and $y = -\left(\frac{x+7455}{18}\right)$ intersect the chord

For $y = -\left(\frac{x+6172}{18}\right)$

Find the x co-ordinate

$$m'x + c' = mx + c$$

$$-\tfrac{x}{18} - \tfrac{3086}{9} = 18x - 1104$$

$$18x + \frac{x}{18} = 1104 - \frac{3086}{9}$$

$$\frac{325x}{18} = \frac{(9936-3086)}{9}$$

$$325x = 18\left(\frac{6850}{9}\right)$$

$$x = 2\left(\frac{6850}{325}\right)$$

$$x = \frac{13700}{325} = \frac{548}{13}$$

Find y co-ordinate given $x = \frac{548}{13}$

$$y = mx + c$$

$$y = 18\left(\frac{548}{13}\right) - 1104$$

$$y = \frac{(9864-(1104\times 13))}{13}$$

$$y = \frac{(9864-14352)}{13}$$

$$y = -\left(\frac{4488}{13}\right)$$

The intersection point is at $\left(\frac{548}{13}, -\frac{4488}{13}\right)$.

Similarly, the intersection points for the equations $y = -\left(\frac{x+6787}{18}\right)$ and $y = -\left(\frac{x+7455}{18}\right)$ are $\left(\frac{2617}{65}, -\frac{24654}{65}\right)$ and $\left(\frac{12417}{325}, -\frac{135294}{325}\right)$ respectively.

Step 6: Determine the vertebra which is furthest away from the L1-L5 chord.

Calculate the distance between the intersection point $\left(\frac{548}{13}, -\frac{4488}{13}\right)$ and L2

Using Pythagoras:

$$h_{L2}{}^2 = (x_1 - x_2)^2 + (y_1 - y_2)^2$$

$$h_{L2}{}^2 = (\tfrac{548}{13} - 38)^2 + (-\tfrac{4488}{13} - (-345))^2$$

$$h_{L2}{}^2 = (\tfrac{(548-(38\times 13))}{13})^2 + (\tfrac{((345\times 13)-4488)}{13})^2$$

$$h_{L2}{}^2 = (\tfrac{(548-494)}{13})^2 + (\tfrac{(4485-4488)}{13})^2$$

$$h_{L2}{}^2 = (\tfrac{54}{13})^2 + (\tfrac{-3}{13})^2$$

$$h_{L2} = \sqrt{(\tfrac{54}{13})^2 + (\tfrac{-3}{13})^2}$$

$$h_{L2} = \sqrt{\tfrac{2916}{169} + \tfrac{9}{169}} = \sqrt{\tfrac{2925}{169}} = \tfrac{5\sqrt{117}}{13}$$

$h_{L2} = \frac{5\sqrt{117}}{13}$ = 4.160 (to 3 decimal places)

Similarly,

$h_{L3} = \frac{\sqrt{4693}}{13}$ = 5.270 (to 3 decimal places)

$h_{L4} = \frac{94\sqrt{13}}{65}$ = 5.214 (to 3 decimal places)

The arc rise is the greatest distance, which is $h_{L3} = \frac{\sqrt{4693}}{13}$

Step 7S: Calculate the angle of curvature (β)

$$\beta = 2 \arcsin\left(\frac{4h_{L3}l}{4(h_{L3})^2 + l^2}\right)$$

$$\beta = 2 \arcsin\left(\frac{4(\frac{\sqrt{4693}}{13})40\sqrt{13}}{4(\frac{\sqrt{4693}}{13})^2 + (40\sqrt{13})^2}\right)$$

$$\beta = 2\arcsin\left(\frac{160(\frac{\sqrt{61009}}{13})}{4(\frac{4693}{169})+20800}\right)$$

$$\beta = 2\arcsin\left(\frac{3040}{\frac{1444}{13}+20800}\right)$$

β = 16.7° (to 1 decimal place)

Step 7L: Find the distance (l_1) between L5 and the intersection point $(\frac{2617}{65}, -\frac{24654}{65})$

$$l_1 = \sqrt{((\Delta x)^2 + (\Delta y)^2)}$$

$$l_1 = \sqrt{((\frac{2617}{65} - 36)^2 + (-\frac{24654}{65} - (-456))^2)}$$

$$l_1 = \sqrt{((\frac{2617}{65} - \frac{2340}{65})^2 + (-\frac{24654}{65} + \frac{29640}{65})^2)}$$

$$l_1 = \sqrt{((\frac{277}{65})^2 + (\frac{4986}{65})^2)}$$

$$l_1 = \sqrt{(\frac{76729}{4225} + \frac{24860196}{4225})} = \sqrt{\frac{24936925}{4225}}$$

$$l_1 = \sqrt{\frac{997477}{169}} = \frac{\sqrt{997477}}{13}$$

Step 8L: Calculate the angle of curvature (γ)

$$\gamma = 2\arctan\left(\frac{h_{L3}}{l_1}\right) + 2\arctan\left(\frac{h_{L3}}{l-l_1}\right)$$

$$\gamma = 2\arctan\left(\frac{\frac{\sqrt{4693}}{13}}{\frac{\sqrt{997477}}{13}}\right) + 2\arctan\left(\frac{\frac{\sqrt{4693}}{13}}{40\sqrt{13}-\frac{\sqrt{997477}}{13}}\right)$$

$$\gamma = 2\arctan\left(\sqrt{\frac{4693}{997477}}\right) + 2\arctan\left(\frac{\frac{\sqrt{4693}}{13}}{\frac{520\sqrt{13}-\sqrt{997477}}{13}}\right)$$

$$\gamma = 2\arctan\left(\sqrt{\frac{4693}{997477}}\right) + 2\arctan\left(\frac{\sqrt{4693}}{520\sqrt{13}-\sqrt{997477}}\right)$$

γ = 16.8° (to 1 decimal place)

5.4 Sample Results

The results of the calculations performed by the developed software for the experiment are provided in Appendix 1. Figure 5-7 and Figure 5-8 show screenshots from the developed software of the spinal curvatures from male subject 13. Table 5-2 shows the thoracolumbar offset and thoracic and lumbar curvature angles generated by the software for the same subject.

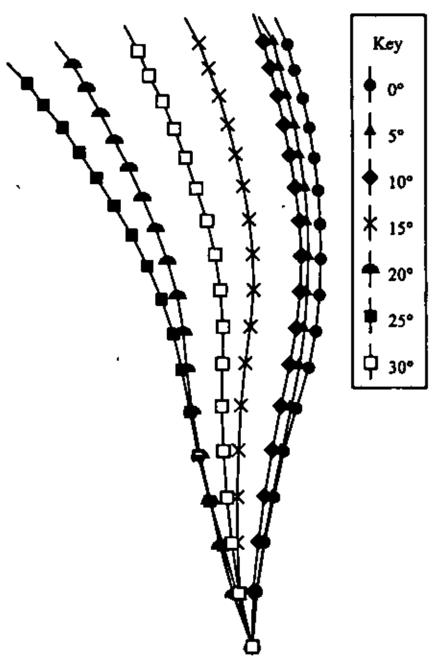

Figure 5-7 - Uphill Spinal Curvatures for Male Subject 13

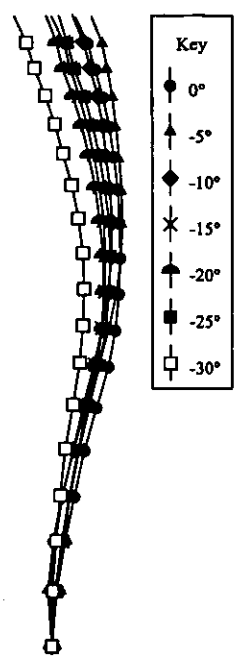

Figure 5-8 - Downhill Spinal Curvatures for Male Subject 13

Table 5-2 - Results for Male Subject 13

Surface Angle	Thoracolumbar Offset	T1-T12 Thoracic Curvature		L1-L5 Lumbar Curvature	
		Shoun Angle	Leroux Angle	Shoun Angle	Leroux Angle
-30°	3.3°	35.8°	35.8°	6.4°	8.0°
-25°	-0.7°	37.9°	37.9°	8.1°	8.1°
-20°	0.4°	34.2°	35.3°	7.1°	7.1°
-15°	0.0°	35.2°	35.2°	10.1°	12.6°
-10°	-2.0°	35.9°	35.9°	18.2°	18.3°
-5°	-3.7°	36.8°	38.0°	23.4°	23.5°
0°	-2.2°	34.9°	34.9°	10.1°	10.2°
5°	-0.7°	31.3°	31.3°	10.7°	13.2°
10°	-0.2°	34.2°	35.4°	11.2°	11.3°
15°	5.9°	36.1°	36.1°	20.2°	25.2°
20°	17.8°	31.3°	32.4°	11.2°	11.2°
25°	22.4°	32.1°	33.2°	2.9°	4.0°
30°	11.4°	35.0°	35.0°	12.8°	15.9°

5.5 Conclusions

Experiments to determine how people maintain balance when standing on different surface gradients and when wearing different footwear have been described. The experiment measured 39 subjects on surface gradients of -30° to +30° in 5° increments. Additionally, female subjects were asked to repeat the experiment in two sets of high heeled shoes.

The software provided with the SpinalMouse® has major limitations and subsequently, new improved software has been developed. The new software accepts as input the files exported from the SpinalMouse® software and for each spinal curvature, it generates the thoracolumbar offset angle and the thoracic and lumbar angles of curvature. The following chapters analyse the results from these experiments.

Chapter 6 - Effects of Surface Gradient and Footwear on Thoracolumbar Offset

This chapter focuses on the results of the experiment into the effects of surface gradient and the effects of wearing heeled shoes on the thoracolumbar offset of the spine as described in Section 4.5.

Changes in the thoracolumbar offset indicate that the subject's centre of mass has moved. Movement of the centre of mass will cause increased muscle activity due to the centre of mass not being directly above the pelvis.

6.1 Methodology and Definitions

Thoracolumbar offset, for this study, is defined to be the anticlockwise angle (Φ) that the line connecting the L5 and T1 vertebrae makes with the vertical (see Figure 4-6).

The following statistical analyses were completed:

- Paired *t*-tests to determine whether surface gradient had an effect on the male thoracolumbar offset angle.
- Paired *t*-tests to determine whether surface gradient had an effect on the female thoracolumbar offset angle.
- Independent two-sample *t*-tests of the difference between mean male and female thoracolumbar offset at each surface angle.
- Paired *t*-tests to determine whether surface gradient had an effect on the female thoracolumbar offset angle when the subjects wore heeled shoes.
- One-way ANOVA for repeated measures was used to compare the effect of each pair of shoes on the thoracolumbar offset of the spine at each surface angle.

Analysis was performed using SPSS® software to calculate. Student's *t*-tests. For the independent *t*-tests a Levene's test p-value of 0.05 was taken to mean equal variances could not be assumed and the unequal variances method of *t*-tests was used.

For ANOVA analysis, Mauchly's test of sphericity was used to determine sphericity (equality of the variances between groups). If Mauchly's test was significant i.e. sphericity could not be assumed, the significance level of the Lower-bound test was used to determine whether the null hypothesis could be rejected.

Notations

The following notations are used throughout this chapter.

- θ is defined to be the angle of the surface to the horizontal (where $-30° \leq \theta \leq 30°$). Negative values of θ represent a downhill surface, while positive values represent an uphill surface.

- $\overline{\phi}_{\theta}$ is defined to be the mean thoracolumbar offset angle at a surface angle of θ standing barefoot. For example, the mean thoracolumbar offset angle when standing on a surface inclined at 20° is represented by $\overline{\phi}_{20}$. Larger values of $\overline{\phi}_{\theta}$ indicate the subjects lean further forward, negative values of $\overline{\phi}_{\theta}$ indicate that the subjects were leaning backward.

- $\overline{d}_{\theta}$ is used to denote the difference between $\overline{\phi}_{\theta}$ and $\overline{\phi}_{0}$. i.e. $\overline{d}_{15} = \overline{\phi}_{15} - \overline{\phi}_{0}$.

- $\overline{\phi}_{(footwear,\theta)}$ is used to represent the mean female thoracolumbar offset angle standing in *footwear* on a surface gradient of θ. The *footwear* is either the small heels (represented by *sh*) or the high heels (represented by *hh*) as described in

Section 5.2. For example, $\overline{\phi}_{(hh,-30)}$ indicates the mean thoracolumbar offset of female subjects wearing high heeled shoes when standing on a surface inclined at -30°.

- $\overline{d}_{(footwear,\theta)}$ is used to define the difference between $\overline{\phi}_{(footwear,\theta)}$ and $\overline{\phi}_{(footwear,0)}$.
  i.e. $\overline{d}_{(sh,25)} = \overline{\phi}_{(sh,25)} - \overline{\phi}_{(sh,0)}$.

The results have been split by gender and footwear resulting in four groups; barefoot males, barefoot females, females wearing small heeled shoes and females wearing high heeled shoes. This enables comparisons between genders and analysis into the effect of heeled shoes on thoracolumbar offset.

6.2 Male and Female Thoracolumbar Offset Results

This section describes the changes in the thoracolumbar offset experienced by male and female subjects when they stood on different surface gradients. For each gender a paired *t*-test is used to compare the effect of surface gradient on the thoracolumbar spine. Table 6-1 and Table 6-2 show the mean thoracolumbar offset angle for each surface gradient ($\overline{\phi}_\theta$) and the difference between the thoracolumbar offset angle at each surface gradient and the thoracolumbar offset angle at the horizontal gradient ($\overline{d}_\theta$) for males and females respectively. Table 6-3 shows the results of an independent *t*-test to compare how male and female mean thoracolumbar offset angles differ when they stand on each surface gradient.

The spinal curvatures of males and females standing on uphill surface gradients can be seen in Figure 6-1. The figure shows that, for gradients of 20° and steeper, the thoracolumbar offset angle of both males and females increases as the surface gradient increases.

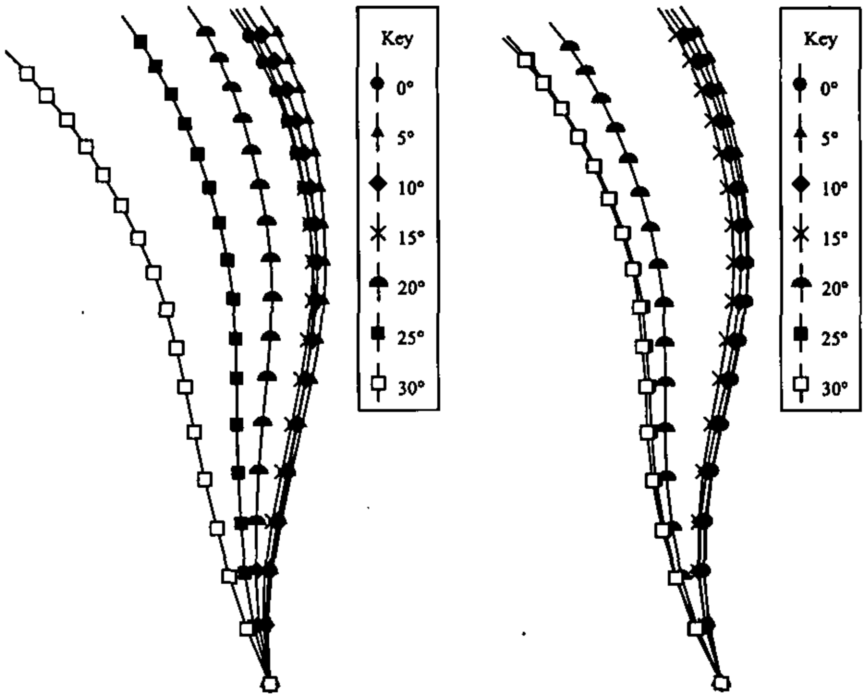

Figure 6-1 - Average male spinal curves on the left and average female spinal curves on the right

Table 6-1 and Table 6-2 confirm the effects of surface gradient on the thoracolumbar offset angle and show that it is significantly greater on surfaces greater than 15° for females and 20° for males than when standing on a horizontal surface.

The male subjects' thoracolumbar offset angle while standing on surface gradients of 5°, -10° and -15° are significantly different from standing on a horizontal surface ($P < 0.05$) (see Table 6-1). The difference between male thoracolumbar offset while standing on surfaces between 20° and 30° and a horizontal surface is highly significant ($P < 0.001$) (see Table 6-1). Although all male subjects leant further forward on the 30° surface than when they stood on a horizontal surface ($\overline{\phi_{30}} > \overline{\phi_0}$), at the higher surface inclination angles there are also large variances (see Table 6-1 and Figure 6-2). This arises as some subjects are severely affected by the change in surface angle whereas other subjects are able to stand almost as erect on a 30° slope as when they are standing on horizontal ground.

Table 6-1 - Effects of Surface Gradient on Thoracolumbar Offset Angle of Barefoot Males

Surface Angle (θ)	Males Barefoot		
	$\overline{\phi}_\theta$	$\overline{d}_\theta$	
	mean (S.D.)	mean (S.D.)	*p*-value
-30	2.0° (3.0°)	-0.4° (2.7°)	0.354
-25	1.8° (3.4°)	-0.6° (2.7°)	0.130
-20	1.8° (3.2°)	-0.6° (2.1°)	0.066
-15	1.8° (3.2°)	-0.6° (1.8°)	0.030
-10	1.6° (3.4°)	-0.9° (2.3°)	0.022
-5	2.5° (3.4°)	0.1° (2.4°)	0.847
0	2.5° (2.8°)	N/A	
5	1.7° (3.2°)	-0.8° (2.0°)	0.019
10	2.2° (2.9°)	-0.3° (2.0°)	0.390
15	2.8° (3.5°)	0.3° (3.0°)	0.497
20	6.5° (5.6°)	4.1° (5.8°)	<0.001
25	12.4° (9.6°)	9.9° (9.6°)	<0.001
30	22.2° (18.0°)	19.7° (18.0°)	<0.001

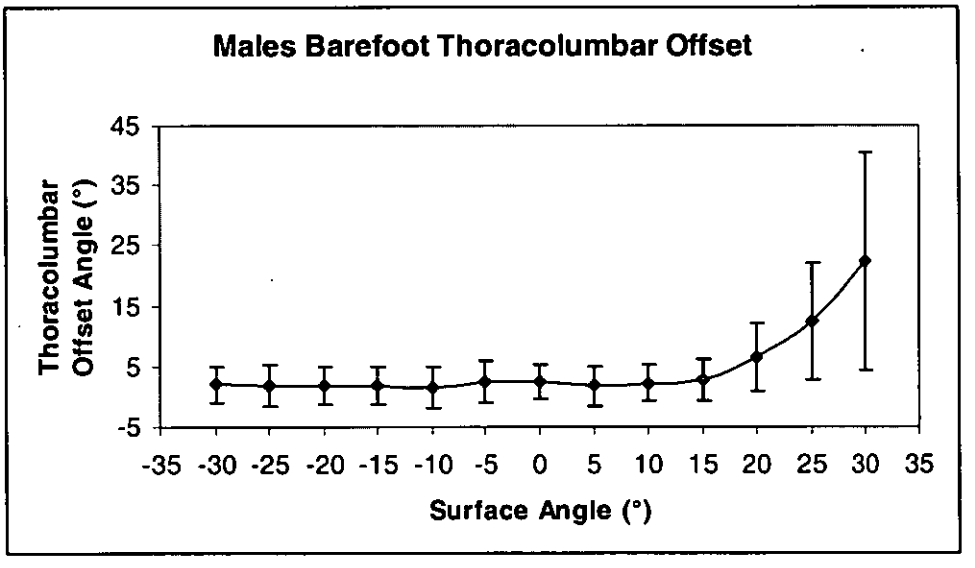

Figure 6-2 - Graph showing the effect of Surface Inclination on the Male Thoracolumbar Offset Angle

There are highly significant differences for female thoracolumbar offset $\overline{d}_\theta$ for 15° ≤ θ ≤ 30° and for $\overline{d}_{(-20)}$ (P < 0.01) (see Table 6-2). Additionally, female subjects showed significant differences for $\overline{d}_{(-10)}$ and $\overline{d}_{(-15)}$ (P < 0.05) and $\overline{d}_{(-25)}$ (P = 0.055). Female subjects, like the male subjects, would lean further forward when standing on a surface inclined at 30° or the highest inclination each individual could manage than when standing on a horizontal surface. It is worth noting that there were six female subjects that were unable to stand on the 30° slope (n = 13 for $\theta = 30°$). Also like the male subjects, the standard deviation increases as the surface increases (see Figure 6-3). The standard deviation decreases for the 30° surface because it was the six females that could not manage to stand on the 30° that were leaning further forward on the 25° surface.

Table 6-2 - Effects of Surface Gradient on Thoracolumbar Offset Angle of Barefoot Females

Surface Angle (θ)	Female Barefoot		
	$\overline{\phi_\theta}$	$\overline{d_\theta}$	
	mean (S.D.)	mean (S.D.)	*p*-value
-30	2.4° (5.0°)	-1.0° (3.0°)	0.065
-25	2.5° (4.7°)	-0.9° (2.9°)	0.055
-20	1.7° (5.1°)	-1.6° (3.2°)	0.003
-15	2.4° (4.3°)	-1.0° (2.7°)	0.028
-10	2.3° (4.4°)	-1.1° (2.5°)	0.012
-5	3.2° (4.6°)	-0.2° (2.6°)	0.607
0	3.4° (4.3°)	N/A	
5	3.3° (4.4°)	-0.1° (3.1°)	0.821
10	4.2° (5.7°)	0.8° (3.8°)	0.176
15	5.8° (5.8°)	2.4° (4.6°)	0.002
20	14.1° (10.1°)	10.7° (9.9°)	<0.001
25	17.8° (15.2°)	14.3° (15.0°)	<0.001
30†	19.1° (9.5°)	16.0° (11.4°)	<0.001

† n = 13 for θ = 30°

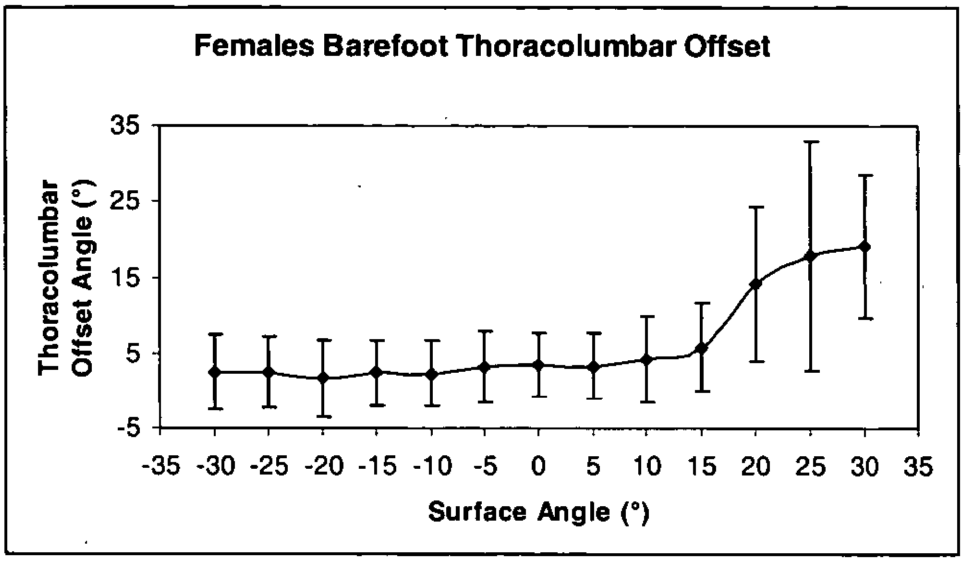

Figure 6-3 - Graph Showing the Effect of Surface Inclination on the Female Thoracolumbar Offset Angle

The female thoracolumbar offset angle is, for a majority of the measured surfaces, greater than the male thoracolumbar offset angle (see Table 6-3 and Figure 6-4). The male and female thoracolumbar offset angles are similar for the downhill surfaces. However for uphill surfaces of 5° to 25° female thoracolumbar offset is either significantly greater ($p<0.05$) or greater ($p<0.075$) than male thoracolumbar offset for the uphill surfaces. The 15° and 20° surfaces exhibit the largest differences between the male and female thoracolumbar offsets. When standing on the 15° surface the female subjects were leaning significantly further forward than at lower inclines, whereas for males the first angle where the forward lean is significant is at 20°. So at 15° surface inclination the female subjects are being significantly affected by the surface inclination whereas the males are not; while at 20° surface inclination, the females are leaning even further forward and the males have just started leaning further forward.

Table 6-3 – Differences between Male and Female Thoracolumbar Offset Angle for Different Surface Angles

Surface Angle (θ)	Female $\bar{\phi}_\theta$ - Male $\bar{\phi}_\theta$	
	mean	*p*-value
-30	0.3°	0.726
-25	0.6°	0.489
-20	-0.1°	0.942
-15	0.5°	0.530
-10	0.7°	0.405
-5	0.6°	0.490
0	0.9°	0.268
5	1.6°	0.071
10	2.0°	0.053
15	3.0°	0.007
20	7.5°	<0.001
25	5.4°	0.073
30	-3.1°	0.366

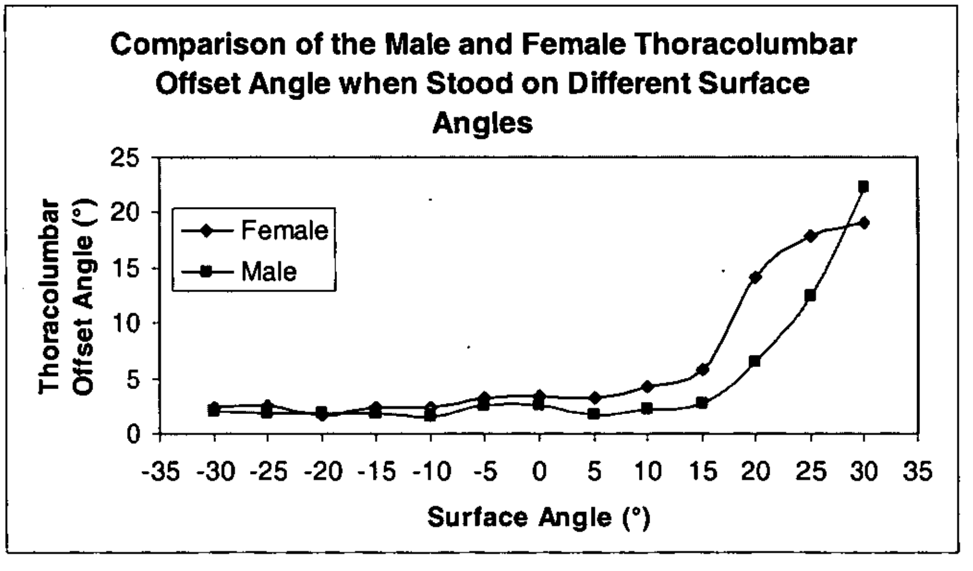

Figure 6-4 - Graph Showing the Effects of Surface Inclination on the Male and Female Thoracolumbar Offset Angle

Leaning forward is not a uniform behaviour for all subjects as θ increases. Some subjects would lean further forwards as the surface gradient increased, other subjects would stay in almost normal upright posture regardless of the surface angle although a majority of the subjects would maintain normal upright posture until a certain critical surface gradient, at which point they would start to lean further forwards as the surface gradient increased. The highest thoracolumbar offset changes are exhibited by some of the tallest subjects, however not all of the tall subjects exhibited this increased change.

6.3 The Effects of Footwear on Female Thoracolumbar Offset

This section describes the changes to thoracolumbar offset angle caused by footwear to female subjects when they stood on different surface gradients. Firstly, the effect of surface gradient on mean thoracolumbar offset angle in females wearing small heeled and high heeled shoes is investigated. Secondly, for each surface gradient, one-way ANOVA for repeated measures was used to compare the effect of each pair of shoes on the thoracolumbar offset of the spine.

Table 6-4 and Table 6-5 show the effect of surface inclination on the thoracolumbar offset in females wearing small heeled and high heeled shoes respectively.

When the female subjects wore the small heeled shoes the surface inclination significantly decreased the thoracolumbar offset angle for many of the measured surface angles (see Table 6-4). Apart from when standing on the 20° surface the *t*-test *p*-value is less than 0.08. Standing on uphill surfaces (excluding 20° and 30°) in small heeled shoes causes a significant or highly significant decrease in thoracolumbar offset than when standing on the horizontal in small heeled shoes. At 30° surface inclination the thoracolumbar offset of females wearing small heeled shoes was greater than when they were standing on a horizontal surface.

Table 6-4 – Effects of Surface Gradient on Thoracolumbar Offset Angle of Females Wearing Small Heels

Surface Angle (θ)	Females Wearing Small Heels		
	$\overline{\phi}_{(sh,\theta)}$	$\overline{d}_{(sh,\theta)}$	
	mean (S.D.)	mean (S.D.)	*p*-value
-30*	1.2° (4.4°)	-1.4° (3.2°)	0.057
-25	2.5° (4.1°)	-1.1° (3.7°)	0.069
-20	2.7° (4.2°)	-0.9° (2.6°)	0.032
-15	2.8° (4.5°)	-0.8° (2.4°)	0.063
-10	2.4° (4.6°)	-1.2° (2.6°)	0.010
-5	2.5° (3.9°)	-1.1° (2.6°)	0.009
0	3.6° (4.5°)	N/A	
5	2.2° (5.3°)	-1.4° (2.6°)	0.002
10	2.5° (5.0°)	-1.1° (3.1°)	0.036
15	2.5° (4.9°)	-1.1° (2.5°)	0.009
20	3.1° (4.4°)	-0.5° (2.7°)	0.250
25	2.4° (4.2°)	-1.1° (2.8°)	0.015
30*	5.0° (6.3°)	2.5° (6.3°)	0.080

* n = 11 for θ = -30° and 30°

Standing on downhill surfaces in small heeled shoes always caused a decrease in thoracolumbar offset compared to when standing on the horizontal in small heeled shoes. This decrease was significant at -20° and highly significant at -5° and -10°; for the remaining measured downhill surfaces $p < 0.07$.

Similarly, when the female subjects wore the high heeled shoes the surface inclination decreased the thoracolumbar offset angle for all measured downhill surfaces and all uphill surfaces up to and including 20° (see Table 6-5). The decrease in thoracolumbar offset from standing on downhill surfaces is not significant for any of the measured surfaces and for the uphill surfaces is only significant for the 20° surface. However surfaces of 5° and 15° show decreases that are almost significant. The surfaces of 25° and 30° show an increase in the thoracolumbar offset compared to when standing on the horizontal for females wearing high heeled shoes, and this increase is highly significant ($p<0.01$) for the 30° surface.

Table 6-5 - Effects of Surface Gradient on Thoracolumbar Offset Angle of Females in High Heels

Surface Angle (θ)	Females High Heels Inclination		
	$\overline{\phi}_{(hh,\theta)}$	$\overline{d}_{(hh,\theta)}$	
	mean (S.D.)	mean (S.D.)	*p*-value
-30*	0.6° (4.1°)	-0.1° (4.8°)	0.947
-25+	3.6° (3.8°)	-0.9° (4.5°)	0.294
-20^	3.4° (4.4°)	-0.7° (3.8°)	0.279
-15	3.3° (3.7°)	-0.6° (4.0°)	0.362
-10	3.3° (4.0°)	-0.6° (3.4°)	0.260
-5	3.1° (4.0°)	-0.9° (3.6°)	0.160
0	3.9° (4.4°)	N/A	
5	2.9° (3.8°)	-1.1° (3.3°)	0.061
10	2.9° (4.5°)	-1.0° (3.7°)	0.106
15	2.8° (4.4°)	-1.1° (3.4°)	0.055
20^	2.5° (4.1°)	-1.6° (3.3°)	0.008
25+	5.0° (4.1°)	0.6° (5.4°)	0.588
30†	9.5° (6.2°)	8.3° (7.8°)	0.008

* n = 4 for θ = -30°
\+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 5 for θ = 30°

The decrease in thoracolumbar offset on non-horizontal surfaces when wearing either of the pairs of heeled shoes is possibly caused by an uncertainty about the posture to adopt on these surfaces. Unlike standing on horizontal ground in heeled shoes, standing on non-horizontal surfaces in heeled shoes might have been an uncommon scenario for the subjects.

Table 6-6 shows the mean thoracolumbar offset angle of the group of females for each surface gradient and each pair of shoes or barefoot.

Table 6-6 - Thoracolumbar Offset for Females Wearing Different Footwear on Different Surfaces

Surface Angle (θ)	Female		
	$\overline{\phi}_{\theta}$ mean (S.D.)	$\overline{\phi}_{(sh,\theta)}$ mean (S.D.)	$\overline{\phi}_{(hh,\theta)}$ mean (S.D.)
-30	2.4° (5.0)	1.2° (4.4)	0.6° (4.1)
-25	2.5° (4.7)	2.5° (4.1)	3.6° (3.8)
-20	1.7° (5.1)	2.7° (4.2)	3.4° (4.4)
-15	2.4° (4.3)	2.8° (4.5)	3.3° (3.7)
-10	2.3° (4.4)	2.4° (4.6)	3.3° (4.0)
-5	3.2° (4.6)	2.5° (3.9)	3.1° (4.0)
0	3.4° (4.3)	3.6° (4.5)	3.9° (4.4)
5	3.3° (4.4)	2.2° (5.3)	2.9° (3.8)
10	4.2° (5.7)	2.5° (5.0)	2.9° (4.5)
15	5.8° (5.8)	2.5° (4.9)	2.8° (4.4)
20	14.1° (10.1)	3.1° (4.4)	2.5° (4.1)
25	17.8° (15.2)	2.4° (4.2)	5.0° (4.1)
30	19.1° (9.5)	5.0° (6.3)	9.5° (6.2)

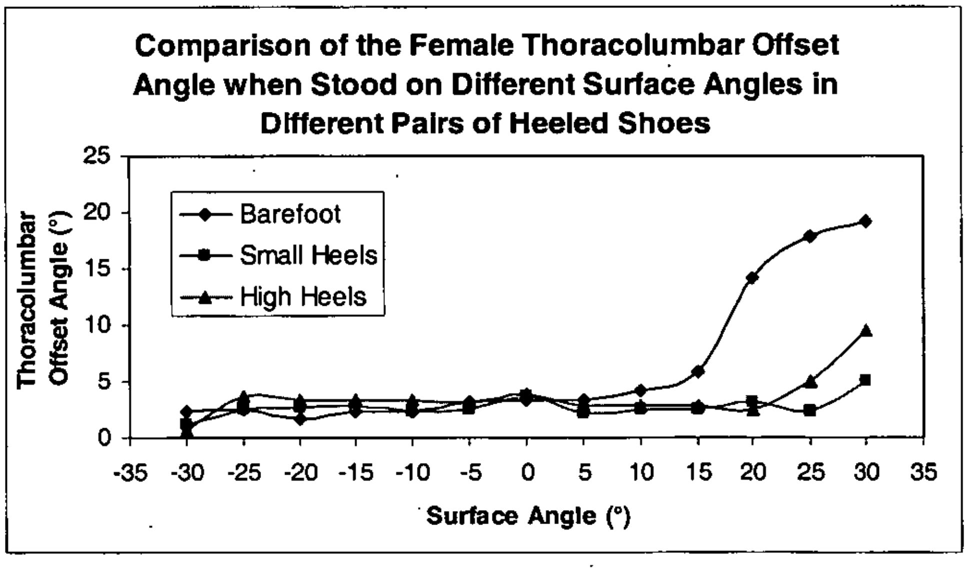

Figure 6-5 - Graph Showing the Effects of Heeled Footwear and Surface Inclination on the Female Thoracolumbar Offset Angle

The data shown in Table 6-6 and Figure 6-5 show that wearing heeled shoes on uphill surfaces decreases the effect that surface inclination has on the thoracolumbar offset angle. When females wore the small heeled shoes their average thoracolumbar offset angle remained between 2.2° and 3.6° except at the extremes of the measurement range where it fell to 1.2° at -30° and rose to 5.0° at 30°. Similarly when the female subjects wore the high heeled shoes their average thoracolumbar offset angle remained between 2.5° to 3.9° falling to 0.6° at -30° and rising to 5.0° at 25° and 9.5° at 30°.

Heeled shoes have minimal effect on the thoracolumbar offset angle when standing on horizontal ground. The largest differences to the thoracolumbar offset angle due to footwear occur at surface angles which are greater than 20°. Although the mean figures for barefoot results increase greatly, the standard deviation of those results also increases, as not all subjects reacted similarly. However the results for wearing heeled footwear maintain a more uniform standard deviation.

It appears that wearing heeled shoes enables the subjects to stand on steeper uphill surfaces without the thoracolumbar offset angle increasing because the angle of the foot is altered such that balance can be maintained through the ankle rather than altering the trunk configuration.

The results also show that the thoracolumbar offset is lower when wearing the small heeled shoes than when wearing the high heeled shoes for most of the measured surface gradients.

The final part of the investigation into the effects of footwear and surface gradient on thoracolumbar offset focuses on how footwear affects the thoracolumbar offset of females that are stood on different surface gradients. Table 6-7 shows the pairwise comparisons for each surface angle between being barefoot or wearing the small heeled pair of shoes or wearing the high heeled pair of shoes.

Table 6-7 - Pairwise Comparison of Female Thoracolumbar Offset When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{\phi_\theta} - \overline{\phi_{(sh,\theta)}}$		$\overline{\phi_\theta} - \overline{\phi_{(hh,\theta)}}$		$\overline{\phi_{(sh,\theta)}} - \overline{\phi_{(hh,\theta)}}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	-0.6	NS	-1.1	NS	-0.4	NS
-25+	0.2	NS	-0.0	NS	-0.2	NS
-20^	-1.1	0.024	-1.5	0.022	-0.4	NS
-15	-0.5	NS	-0.6	NS	-0.1	NS
-10	-0.1	NS	-0.9	NS	-0.8	NS
-5	0.8	NS	0.3	NS	-0.6	NS
0	-0.1	NS	-0.4	NS	-0.3	NS
5	1.1	NS	0.3	NS	-0.7	NS
10	1.7	0.007	1.4	0.024	-0.3	NS
15	3.3	<0.001	3.1	<0.001	-0.3	NS
20^	11.3	<0.001	11.9	<0.001	0.7	NS
25+	18.2	<0.001	16.1	<0.001	-2.1	0.038
30†	28.6	0.013	18.6	0.004	-10.1	NS

* n = 4 for θ = -30°
+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

In order for ANOVA to be calculated, for each surface gradient, only those subjects able to stand on that surface gradient barefoot and in both pairs of shoes could be compared. As such the number of subjects compared for the very steep surfaces is lower than for the less steep surfaces.

Table 6-7 clearly shows significant differences ($p < 0.05$) between being barefoot and wearing either pair of shoes, once the surface gradient increases beyond 5°. When standing on surface gradients greater than 5° heeled footwear decreases the amount of thoracolumbar lean exhibited by the subjects. For downhill surfaces there are significant differences between being barefoot and wearing either pair of heeled shoes at a surface gradient of -20°. Interestingly, there is no indication of any significant difference between being barefoot and wearing heeled shoes on horizontal ground.

The differences between the two pairs of heeled shoes $\overline{\Phi}_{(sh,\theta)}$ - $\overline{\Phi}_{(hh,\theta)}$ for -30° ≤ θ ≤ 20° was always less than 1° and except for θ = 20°, $\overline{\Phi}_{(sh,\theta)} < \overline{\Phi}_{(hh,\theta)}$ for all measured surface gradients. Significant differences between wearing small heeled shoes and wearing high heeled shoes only occur at a surface gradient of 25°.

6.4 Conclusions

This analysis reveals that thoracolumbar offset is affected more significantly by steeper uphill surface angles. There is a highly significant ($P < 0.01$) difference in thoracolumbar offset between standing on a horizontal surface and standing on an inclined surface for both genders. A similar difference was not seen when the subjects were standing facing downhill. This high significance which was seen only on the uphill surfaces can be attributed to the limit of the ankle range of motion which has previously been found to be 5 to 20 degrees lower in dorsiflexion than in plantar flexion for both genders [83].

The results also show that a female will generally have a higher thoracolumbar offset than a male when standing on the same surface and that this is significant for most of the uphill surface angles that were tested in the range of (0, 30).

It was also found that as the surface angle increases females will generally have to increase their thoracolumbar offset before males and that at a given highly sloped surface, females will be more affected. A highly significant ($P < 0.01$) difference in thoracolumbar offset exists between standing on a horizontal surface and standing on a surface angle greater than 15° for females and greater than 20° for males. Having a lower dorsiflexion range than males [52] may be the most plausible cause of significantly increased thoracolumbar offset for females at lower uphill surface angles.

For both males and females, significant differences in thoracolumbar offset between standing on a horizontal surface and standing on a non-horizontal surface were found. However, there is not a linear relationship between thoracolumbar offset and surface gradient.

It should be noted that, in extreme cases, when increasing the surface inclination, as though standing facing uphill, a few subjects immediately adopt a forward leaning posture and others' postures remain almost unchanged throughout the experiment. However, the most common behaviour is evident in a majority group of subjects whose postures remain significantly unchanged until a certain threshold surface inclination where at any higher surface inclinations they started to lean forward significantly. For the female subjects the threshold is 15°, for the male subjects it is 20°. When decreasing the surface angle, as though standing facing downhill, subjects' thoracolumbar offset generally remains unaffected.

The thoracolumbar offset is significantly affected by steep inclined surface angles. On horizontal ground, the heel height of the subjects' shoes does not affect the thoracolumbar offset. On steep inclined surfaces heeled shoes significantly decrease the effect that the surface gradient has on female thoracolumbar offset. However, for females to stand on a steeply inclined surface while wearing heeled shoes, their thoracolumbar spine has to lean forward significantly. Also, a correlation between heel height and surface inclination could not be found, i.e. standing on any of the declined surfaces did not have a similar effect on thoracolumbar offset as standing in either of the heeled shoes on the thoracolumbar spine of the female subjects.

It is thought that the general decrease in thoracolumbar offset due to wearing heeled footwear is due to the decreased amount of dorsiflexion required in the ankle to stand on uphill surfaces. Wearing heeled shoes on an uphill surface decreases the amount of dorsiflexion and therefore the thoracolumbar spine has to compensate less in order to maintain balance.

It seems as though the thoracolumbar offset only changes when the limit of dorsiflexion or plantarflexion is reached. In the sample population, maximum dorsiflexion was reached at 15° surface inclination for females, however, when the female subjects wore the small heeled shoes maximum dorsiflexion was not reached until 30° surface inclination and for the high heels not until 25°. Maximum plantarflexion did not appear to be reached in this experiment for any surface in any of the footwear.

Chapter 7 - Effects of Surface Inclination and Footwear on Thoracic and Lumbar Curvatures

This chapter focuses on the results of the experiment into the effect of standing on non-horizontal surfaces on the curvatures of the spine and the effects of wearing high heeled shoes on the curvatures of the spine. Results have been split by gender so that comparisons can be made between males and females.

A flatter spine is less able to bear the load of a person that is lifting something as the weight of the object is not distributed as efficiently as it could be. Also, the weight of the upper body is causing a higher amount of fatigue as its weight requires more energy to keep up. Prolonged periods of fatigue can result in backpain.

7.1 Methodology and Definitions

The thoracic and lumbar angles of curvature, in this study, are measured using the methods described by Leroux *et al* [31] and Shoun [68] (see Section 4.4). The resulting angles of curvature are hereafter referred to as the Shoun angle and the Leroux angle. Both methods base the spinal curves on the arcs of circles. The method described by Shoun bases each curve on the arc of a single circle (see Figure 4-4) whereas the method described by Leroux *et al* bases each curve on the arcs of two circles (see Figure 4-5). Software was developed as part of this research to overcome the limitations of the SpinalMouse® software and to calculate the Shoun angle and the Leroux angle (see Section 5.3). SPSS® is used for the statistical analysis.

The following statistical analyses were completed:

- Paired *t*-tests to determine whether surface gradient had an effect on the male thoracic or lumbar spinal curvatures.

- Paired *t*-tests to determine whether surface gradient had an effect on the female thoracic or lumbar spinal curvatures.
- Independent two-sample *t*-tests of the difference between mean male and female thoracic and lumbar spinal curvatures at each surface angle.
- Paired *t*-tests to determine whether surface gradient had an effect on the thoracic and lumbar curvatures of females wearing heeled shoes.
- One way ANOVA for repeated measures was used to compare the effect of each pair of shoes on the female thoracic and lumbar curvatures at each surface angle.

Analysis was performed using SPSS® software to calculate Student's *t*-tests. For the independent *t*-tests a Levene's test p-value of 0.05 was taken to mean equal variances could not be assumed and the unequal variances method of *t*-tests was used.

For ANOVA analysis, Mauchly's test of sphericity was used to determine sphericity (equality of the variances between groups). If Mauchly's test was significant i.e. sphericity could not be assumed, the significance level of the Lower-bound test was used to determine whether the null hypothesis could be rejected.

Notations

The following notations are used throughout this chapter.

- θ is defined to be the angle of the surface to the horizontal (where $-30° \leq \theta \leq 30°$). Negative values of θ represent a downhill surface, while positive values represent an uphill surface.
- $\overline{\beta}_{(\theta, X\text{-}Y)}$ is defined to be the mean spinal curvature angle, measured using the Shoun method, for the vertebral range X-Y at a

surface angle of θ where X-Y is one of T1-T12, T1-L1, T12-L1 or L1-L5. For example, the mean Shoun curvature angle for the vertebral range of T1-L1 when standing on a surface inclined at 20° is represented by $\overline{\beta}_{(20,\ T1\text{-}L1)}$. Smaller values of $\overline{\beta}_{(\theta,\ X\text{-}Y)}$ indicate flatter spinal curves.

- Similarly, $\overline{\gamma}_{(\theta,\ X\text{-}Y)}$ is defined to be the mean spinal curvature angle, measured using the Leroux method, for the vertebral range X-Y at a surface angle of θ.

- $\overline{\kappa}_{(\theta,\ X\text{-}Y)}$ is used to denote the difference between $\overline{\beta}_{(0,\ X\text{-}Y)}$ and $\overline{\beta}_{(\theta,\ X\text{-}Y)}$. i.e $\overline{\kappa}_{(5,\ T1\text{-}L1)} = \overline{\beta}_{(0,\ T1\text{-}L1)} - \overline{\beta}_{(5,\ T1\text{-}L1)}$.

- Similarly $\overline{\lambda}_{(\theta,\ X\text{-}Y)}$ is used to denote the difference between $\overline{\gamma}_{(0,\ X\text{-}Y)}$ and $\overline{\gamma}_{(\theta,\ X\text{-}Y)}$.

- $\overline{\beta}_{(footwear,\ \theta,\ X\text{-}Y)}$ is used to represent the mean female Shoun angle for the vertebral range *X-Y* when standing in *footwear* on a surface gradient of θ. The *footwear* is either the small heels (represented by *sh*) or the high heels (represented by *hh*) as described in Section 5.2. For example, $\overline{\beta}_{(sh,\ -15,\ T12\text{-}L5)}$ indicates the mean female T12-L5 Shoun angle when standing on a surface inclined at -15° in small heeled shoes.

- Similarly $\overline{\gamma}_{(footwear,\ \theta,\ X\text{-}Y)}$ is used to represent the mean female Leroux angle for the vertebral range *X-Y* when standing in *footwear* on a surface gradient of θ.

- $\overline{\kappa}_{(footwear,\ \theta,\ X\text{-}Y)}$ is used to denote the difference between $\overline{\beta}_{(footwear,\ 0,\ X\text{-}Y)}$ and $\overline{\beta}_{(footwear,\ \theta,\ X\text{-}Y)}$.

  i.e. $\overline{\kappa}_{(sh,\ 20,\ T1\text{-}T12)} = \overline{\beta}_{(sh,\ 0,\ T1\text{-}T12)} - \overline{\beta}_{(sh,\ 20,\ T1\text{-}T12)}$.

- Similarly $\overline{\lambda}_{(footwear,\ \theta,\ X\text{-}Y)}$ is used to denote the difference between $\overline{\gamma}_{(footwear,\ 0,\ X\text{-}Y)}$ and $\overline{\gamma}_{(footwear,\ \theta,\ X\text{-}Y)}$.

The results have been split by gender and footwear resulting in four groups; barefoot males, barefoot females, females wearing small heeled shoes and females wearing high heeled shoes. This enables comparisons between genders and analysis into the effect of heeled shoes on thoracic and lumbar curvatures.

Transition Vertebra

In order to measure the spinal curves the starting and ending vertebra of the curves need to be found. The vertebra that marks the end of the thoracic curve and the start of the lumbar curve is known as the transition vertebra. The transition vertebra occurs in different places in different people. The results of a study by Vialle *et al* [3] are outlined in Table 7-1. Results are for 300 asymptomatic adult subjects, 110 females and 190 males. However, no further breakdown of the transitional vertebra was given (e.g. Male/Female). So it is unknown as to whether in one gender the transitional vertebra is generally higher in the spinal column than in the other gender. The transitional vertebra was determined by inspecting the intervertebral angles. From Table 7-1 it can be seen that the most common transition vertebra is L1 rather than T12 as proposed by Gray [2] and between T11 and T12 by Burton [70]. As such, for each thoracolumbar spinal contour taken in the current study, the contour will be split up on both the standard T12 transition vertebra as well as the L1 vertebra. This results in four curves from each spinal contour, T1-T12 and T1-L1 thoracic curves and T12-L5 and L1-L5 lumbar curves.

Table 7-1 - Transitional Vertebra

Study	**Transitional Vertebra**			
	T11	**T12**	**L1**	**L2**
Stagnara *et al* [16][1]	-	22%	33%	21%
Vialle *et al* [3]	12.6%	23.7%	37.7%	26.0%

Measurement Analysis Technique

Each thoracic and lumbar curve was measured using two techniques; a method described by Leroux *et al* [31] (see Section 4.4) and a method described by Shoun (see Section 4.4). The Shoun method assumes symmetry about the maximum curve rise whereas the Leroux method calculates two angles, one for each side of the maximum curve rise and adds them together, which is more representative of the actual spinal curves. Both methods have been compared against the Cobb angle method (see Section 4.1) used to obtain curvature angles from radiographs [24, 31, 68].

7.2 The Effects of Standing on Different Surface Gradients on the Thoracolumbar Curvatures of Males

This section discusses the changes that were observed to occur to the thoracic and lumbar curves of male subjects while they were standing on a platform that could be inclined/declined up to 30° from the horizontal.

Thoracic Spine

Regardless of measurement technique and measurement range, there is little change – up to 1.7° – in the mean curvature of the male thoracic spine when standing on a downward surface compared to when standing on horizontal ground (see Table 7-2 and Table 7-3). When standing on

[1] The article by Stagnara *et al* only provides the most common transitional vertebra locations and does not provide the information on the remaining 24% of the subjects whose transitional vertebra was not T12, L1 or L2.

inclined surfaces of 5° and 15° there is also little change in the mean male thoracic curvature compared to standing on horizontal ground (up to 1.9°). However, for inclined surfaces greater than 15° there are there is a significant reduction ($p < 0.01$) in the mean male thoracic curvature from standing on horizontal ground, with the clear trend of higher surface inclinations resulting in less thoracic curvature. There is also a significant reduction in male thoracic curvature between 0° and 10° surface inclination.

Leroux *et al* [31] found the thoracic curvature Leroux angle for adolescent females with scoliosis to be 36° (12°) for the T2-T12 vertebral range when using skin-surface markers. Vialle *et al* [3] found the Cobb angle of thoracic curvature for male asymptomatic subjects to be 41.7° (10°) for T4-T12 from radiographic images. D'Osualdo *et al* [24] found the mean angle of kyphosis of kyphosis sufferers was 39° (18°). Opila *et al* [35] found no significant differences in the thoracic curvature between standing in high heels and standing barefoot.

The results of Chapter 6 indicated that males started to lean forward when the surface inclination was 20° and greater. It appears that subjects standing on surfaces inclined at an angle greater than or equal to 20° will lean forwards and have flatter thoracic spines.

Table 7-2 - Shoun's Angle of Males Thoracic Curves

Surface Angle (θ)	Males Shoun Thoracic Angles			
	$\overline{\beta}_{(\theta, T1\text{-}T12)}$	$\overline{\kappa}_{(\theta, T1\text{-}T12)}$	$\overline{\beta}_{(\theta, T1\text{-}L1)}$	$\overline{\kappa}_{(\theta, T1\text{-}L1)}$
-30	43.8 (11.2)	0.7 (9.2)	46.1 (11.1)	1.0 (9.7)
-25	44.4 (12.1)	0.0 (9.3)	46.9 (12.1)	0.3 (9.6)
-20	45.3 (11.1)	-0.8 (6.8)	48.0 (11.1)	-0.8 (7.0)
-15	46.1 (12.0)	-1.7 (8.2)	48.8 (12.4)	-1.6 (8.1)
-10	45.1 (11.5)	-0.6 (6.4)	47.8 (11.6)	-0.7 (6.5)
-5	45.0 (11.1)	-0.5 (6.7)	47.3 (10.8)	-0.1 (6.5)
0	44.5 (9.9)	N/A	47.2 (9.9)	N/A
5	42.7 (10.7)	1.8 (6.0)	45.3 (11.0)	1.9 (6.0)
10	42.1 (10.0)	2.4 (6.0)+	44.5 (10.2)	2.7 (5.6)*
15	44.1 (11.0)	0.4 (7.0)	46.3 (11.3)	0.9 (7.1)
20	38.6 (10.4)	5.9 (6.8)*	39.9 (10.0)	7.3 (7.5)*
25	36.2 (12.0)	8.3 (10.3)*	38.5 (11.8)	8.6 (10.2)*
30	35.6 (12.5)	8.8 (10.2)*	36.9 (12.5)	10.3 (10.9)*

n=20
* - 1% Significance
+ - 5% Significance

Table 7-3 - Leroux's Angle of Males Thoracic Curves

Surface Angle (θ)	Males Leroux Thoracic Angles			
	$\overline{\gamma}_{(\theta, T1\text{-}T12)}$	$\overline{\lambda}_{(\theta, T1\text{-}T12)}$	$\overline{\gamma}_{(\theta, T1\text{-}L1)}$	$\overline{\lambda}_{(\theta, T1\text{-}L1)}$
-30	45.0 (11.1)	0.9 (9.1)	47.4 (10.9)	0.5 (9.5)
-25	45.4 (11.9)	0.5 (9.3)	47.8 (12.3)	0.2 (9.7)
-20	47.1 (10.8)	-1.2 (6.7)	49.2 (11.0)	-1.3 (7.1)
-15	47.1 (12.0)	-1.2 (7.9)	49.6 (12.4)	-1.6 (7.8)
-10	46.2 (11.9)	-0.3 (6.4)	48.7 (12.1)	-0.7 (6.8)
-5	45.9 (11.5)	0.0 (6.8)	48.4 (11.2)	-0.4 (6.8)
0	45.8 (10.1)	N/A	48.0 (10.0)	N/A
5	44.1 (11.1)	1.7 (6.1)	46.7 (11.4)	1.3 (6.3)
10	43.2 (10.2)	2.7 (6.2)*	45.6 (10.1)	2.4 (5.5)*
15	45.3 (11.4)	0.6 (6.9)	47.5 (11.7)	0.5 (7.6)
20	39.8 (10.5)	6.1 (6.8)*	41.1 (10.1)	6.9 (7.8)*
25	37.1 (11.8)	8.7 (10.5)*	39.6 (11.7)	8.4 (9.8)*
30	37.2 (11.6)	8.6 (9.3)*	38.5 (11.9)	9.4 (9.5)*

n=20
* - 1% Significance
+ - 5% Significance

Lumbar Spine

The results show that, like the thoracic spine, the lumbar spine varies little on the downhill surfaces, with the maximum difference between means of 1.6°, regardless of measurement range/technique. When standing on uphill surfaces the mean lumbar curvature angle gradually becomes smaller (flatter) as the surface gradient increases, although is only significantly smaller than the horizontal lumbar curvature when the subjects were standing on surfaces inclined at 30° (see Table 7-4 and Table 7-5).

On horizontal ground, Vialle *et al* [3] found the L1-L5 lumbar Cobb angle to be 41.4° (11°) for asymptomatic males, while Hart and Rose [68] found the L2-L5 Shoun angle to be between 20.8° and 36.7° for asymptomatic subjects.

Table 7-4 - Shoun's Angle of Males Lumbar Curves

Surface Angle (θ)	Males Shoun Lumbar Angles			
	$\overline{\beta}_{(\theta, L1\text{-}L5)}$	$\overline{\kappa}_{(\theta, L1\text{-}L5)}$	$\overline{\beta}_{(\theta, T12\text{-}L5)}$	$\overline{\kappa}_{(\theta, T12\text{-}L5)}$
-30	20.7 (9.3)	0.4 (6.9)	21.8 (11.0)	-0.3 (7.0)
-25	22.2 (9.5)	-1.1 (8.7)	23.1 (10.9)	-1.6 (8.3)
-20	21.8 (10.5)	-0.7 (8.3)	23.0 (11.9)	-1.5 (7.5)
-15	21.3 (12.4)	-0.2 (7.2)	21.8 (13.9)	-0.4 (7.5)
-10	21.4 (9.6)	-0.3 (9.1)	22.1 (11.4)	-0.6 (8.7)
-5	20.5 (10.6)	0.6 (9.8)	21.0 (12.3)	0.5 (9.6)
0	21.1 (12.1)	N/A	21.5 (13.5)	N/A
5	19.8 (11.6)	1.3 (6.9)	20.5 (12.2)	1.0 (6.2)
10	19.7 (9.5)	1.4 (9.3)	20.0 (10.7)	1.5 (9.5)
15	21.6 (10.2)	-0.5 (8.8)	22.8 (11.2)	-1.3 (8.0)
20	18.2 (10.1)	2.8 (6.9)+	19.9 (10.5)	1.6 (6.5)
25	18.3 (9.9)	2.8 (9.8)	19.7 (10.8)	1.7 (10.1)
30	16.4 (6.6)	4.7 (9.3)*	18.4 (7.6)	3.1 (10.3)

n=20
* - 1% Significance
+ - 5% Significance

Table 7-5 - Leroux's Angle of Males Lumbar Curves

Surface Angle (θ)	Males Leroux Lumbar Angles			
	$\bar{\gamma}_{(\theta, L1\text{-}L5)}$	$\bar{\lambda}_{(\theta, L1\text{-}L5)}$	$\bar{\gamma}_{(\theta, T12\text{-}L5)}$	$\bar{\lambda}_{(\theta, T12\text{-}L5)}$
-30	22.5 (8.8)	0.6 (8.1)	23.9 (10.8)	0.2 (8.6)
-25	24.2 (9.7)	-1.1 (10.2)	24.6 (10.7)	-0.6 (9.8)
-20	23.1 (10.3)	0.0 (10.1)	24.5 (11.2)	-0.5 (10.0)
-15	23.0 (11.7)	0.1 (7.5)	23.1 (13.4)	0.9 (7.9)
-10	23.5 (10.1)	-0.4 (9.6)	23.5 (10.8)	0.5 (9.7)
-5	22.0 (10.2)	1.1 (11.2)	22.9 (11.7)	1.2 (12.2)
0	23.1 (12.5)	N/A	24.0 (14.1)	N/A
5	21.2 (11.2)	1.9 (8.1)	21.6 (12.1)	2.4 (8.2)
10	21.4 (9.4)	1.7 (10.7)	21.5 (10.5)	2.5 (11.7)
15	23.1 (9.9)	0.0 (9.0)	24.5 (10.8)	-0.5 (9.4)
20	20.2 (12.0)	2.9 (8.3)+	21.8 (12.3)	2.2 (7.7)
25	20.0 (10.2)	3.1 (9.7)	21.7 (10.7)	2.3 (10.4)
30	17.7 (6.9)	5.4 (10.0)*	19.7 (7.8)	4.3 (10.8)+

n=20
* - 1% Significance
+ - 5% Significance

Thoracic and Lumbar

Both the thoracic and lumbar angles gradually decrease as the surface upon which the subjects are standing increases in gradient. So the subjects' spines are getting flatter. The downhill slopes show very little difference but as the surface gradient increases beyond 15° the thoracic and lumbar spinal curvatures become flatter. The thoracic spine is affected more by the increase in gradient (see Figure 7-1).

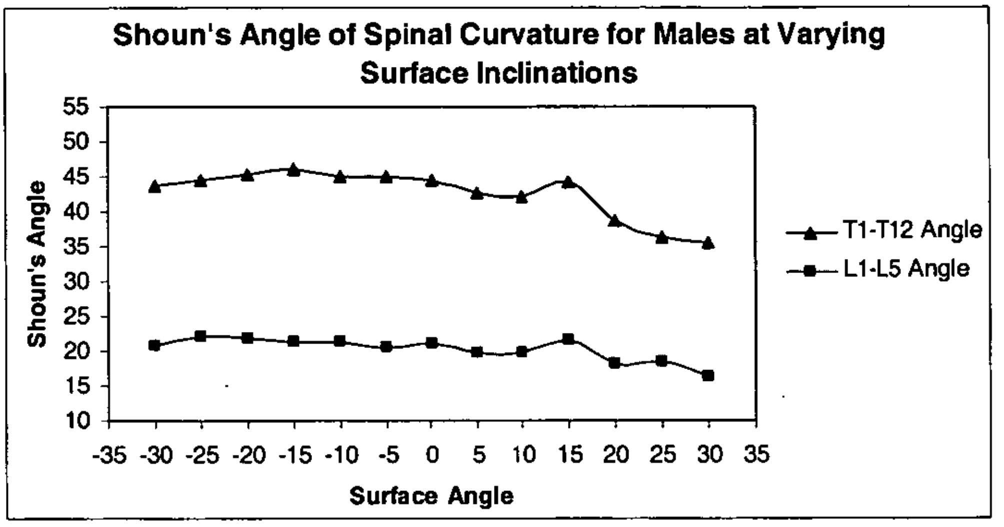

Figure 7-1 - Shoun's Angle of Spinal Curvature for Males

7.3 The Effects of Standing on Different Surface Gradients on the Thoracolumbar Curvatures of Females

This section discusses the changes that were observed to occur to the thoracic and lumbar curves of female subjects while they were standing on a platform that could be inclined/declined up to 30° from the horizontal.

Thoracic Spine

It is observed that the mean female thoracic curvature is affected by standing on downhill surfaces and becomes more curved (see Table 7-6 and Table 7-7). The difference of means between all the downhill surfaces and the horizontal is always greater than 1.7°; with significant differences ($p < 0.05$) between means at surface gradients steeper than -15°. The largest mean angle of curvature of the thoracic spine occurs at -25° of surface inclination for the sample.

When standing on inclined surfaces, the mean female thoracic curvature becomes less curved than when standing on a horizontal surface. When standing on surfaces inclined at 15° and less, the difference between mean thoracic curvature is low (less than 1.4°). However, the difference between means increases at surface inclinations greater than 15°; although it is only significantly different at 20° ($p < 0.01$).

Leroux *et al* [31] found that $\overline{\lambda}_{(0, T2-T12)}$ = 36° (12°) for female AIS patients on horizontal ground when using skin-surface markers. Vialle *et al* [3] found the Cobb angle of kyphosis for female asymptomatic subjects to be 39.0° (10°) for T4-T12 from radiographic images of subjects on horizontal ground. Using skin-surface techniques, D'Osualdo *et al* [24] found the mean angle of kyphosis of kyphosis sufferers was 39° (18°) on horizontal ground.

Table 7-6 - Shoun's Angle of Females Thoracic Curves

Surface Angle (θ)	Females Shoun Thoracic Angles			
	$\overline{\beta}_{(\theta, T1-T12)}$	$\overline{\kappa}_{(\theta, T1-T12)}$	$\overline{\beta}_{(\theta, T1-L1)}$	$\overline{\kappa}_{(\theta, T1-L1)}$
-30	49.8 (10.9)	-4.1 (10.3)+	50.8 (11.6)	-3.5 (9.3)+
-25	50.7 (11.3)	-5.4 (10.4)*	52.5 (11.8)	-5.4 (9.1)*
-20	50.4 (11.1)	-5.1 (11.1)*	52.3 (11.0)	-5.2 (10.1)*
-15	47.6 (10.5)	-2.3 (8.8)	49.5 (11.2)	-2.4 (7.9)
-10	48.3 (10.4)	-3.0 (9.7)	50.2 (11.6)	-3.1 (8.6)+
-5	47.6 (11.3)	-2.3 (9.8)	49.1 (11.7)	-2.0 (8.6)
0	45.3 (13.2)	N/A	47.1 (13.4)	N/A
5	44.6 (11.5)	0.7 (7.9)	46.3 (12.3)	0.9 (7.0)
10	44.3 (12.0)	1.0 (10.1)	45.8 (12.6)	1.4 (9.7)
15	44.7 (11.3)	0.6 (10.9)	45.6 (12.6)	1.3 (10.3)
20	40.6 (12.2)	4.7 (10.1)*	42.1 (14.0)	5.0 (9.9)*
25	43.7 (12.8)	2.4 (9.9)	45.2 (14.3)	2.9 (9.8)
30†	42.4 (13.4)	2.1 (11.2)	42.9 (13.9)	2.4 (10.0)

† n = 13 for θ = 30°

* - 1% Significance

+ - 5% Significance

Table 7-7 - Leroux's Angle of Females Thoracic Curves

Surface Angle (θ)	Females Leroux Thoracic Angles			
	$\overline{\gamma}_{(\theta, T1\text{-}T12)}$	$\overline{\lambda}_{(\theta, T1\text{-}T12)}$	$\overline{\gamma}_{(\theta, T1\text{-}L1)}$	$\overline{\lambda}_{(\theta, T1\text{-}L1)}$
-30	50.4 (11.2)	-3.9 (10.0)+	51.7 (11.8)	-3.6 (9.2)+
-25	51.8 (11.3)	-5.3 (10.5)*	53.4 (11.9)	-5.4 (9.4)*
-20	51.0 (11.1)	-4.5 (11.0)+	53.1 (10.7)	-5.1 (10.1)*
-15	48.3 (10.4)	-1.8 (8.6)	50.2 (11.1)	-2.1 (8.0)
-10	48.9 (10.8)	-2.4 (10.0)	50.7 (11.7)	-2.7 (8.7)
-5	48.6 (11.2)	-2.2 (10.3)	50.3 (11.6)	-2.2 (8.9)
0	46.5 (13.3)	N/A	48.1 (13.5)	N/A
5	45.6 (11.5)	0.9 (7.5)	47.0 (12.1)	1.0 (7.0)
10	45.2 (12.2)	1.3 (10.5)	46.7 (12.5)	1.3 (9.9)
15	45.5 (11.2)	1.0 (11.3)	46.7 (12.3)	1.3 (10.4)
20	41.5 (12.3)	5.0 (10.4)*	42.8 (14.1)	5.2 (10.3)*
25	44.5 (12.5)	2.8 (10.2)	46.0 (14.6)	2.9 (10.1)
30†	43.2 (13.4)	1.9 (11.6)	43.4 (13.8)	2.6 (10.2)

† n = 13 for $\theta = 30°$

* - 1% Significance

\+ - 5% Significance

Lumbar Spine

The mean lumbar curvature of females standing on downhill surfaces shows very little change, except for at -20° which has up to a 3.4° increase between means when using the Leroux method and the T12-L1 range (see Table 7-8 and Table 7-9). For uphill surfaces the mean lumbar curvature becomes less curved at surface angles greater than 15° and significantly less curved at 30° ($p < 0.01$ for L1-L5 range and $p < 0.05$ for T12-L5 range).

On horizontal ground, Vialle *et al* [3] found the L1-L5 Cobb angle to be 46.2° (11°) for asymptomatic females, while Hart and Rose [68] found the L2-L5 Shoun angle to be between 20.8° and 36.7° for asymptomatic subjects. Leroux *et al* [31] found the mean T9-S1 Leroux angle to be 51° (17°) for 124 female subjects with AIS. Franklin *et al* [36] found the lumbar angle of 15 asymptomatic females standing on horizontal ground to be 41.1° (8.8°) and when the subjects' heels were raised by 5.1 cm their lumbar angle decreased to 38.0° (8.2°).

Table 7-8 - Shoun's Angle of Females Lumbar Curves

Surface Angle (θ)	Females Shoun Lumbar Angles			
	$\overline{\beta}_{(\theta, L1\text{-}L5)}$	$\overline{\kappa}_{(\theta, L1\text{-}L5)}$	$\overline{\beta}_{(\theta, T12\text{-}L5)}$	$\overline{\kappa}_{(\theta, T12\text{-}L5)}$
-30	30.0 (12.3)	-1.4 (15.7)	33.3 (12.4)	-1.2 (15.4)
-25	28.6 (9.1)	0.1 (13.0)	32.5 (10.0)	-0.4 (11.9)
-20	31.1 (10.6)	-2.4 (13.1)	34.2 (10.3)	-2.1 (11.6)
-15	27.9 (10.0)	0.9 (11.7)	31.9 (10.9)	0.2 (10.9)
-10	27.6 (9.7)	1.1 (14.1)	32.3 (9.4)	-0.2 (13.6)
-5	29.6 (9.6)	-0.9 (10.9)	33.2 (9.8)	-1.1 (10.8)
0	28.7 (11.0)	N/A	32.1 (11.1)	N/A
5	26.4 (9.0)	2.4 (12.5)	30.9 (9.9)	1.2 (12.9)
10	29.4 (10.8)	-0.7 (14.5)	33.7 (10.6)	-1.6 (12.8)
15	28.6 (9.8)	0.1 (12.8)	32.6 (10.4)	-0.5 (11.9)
20	25.6 (10.4)	3.1 (14.7)	30.1 (12.1)	2.0 (14.7)
25	24.4 (10.2)	4.2 (15.5)	27.8 (10.2)	4.0 (14.3)
30†	19.5 (9.0)	9.4 (15.4)*	24.3 (9.8)	7.6 (16.7)+

† n = 13 for θ = 30°

* - 1% Significance

\+ - 5% Significance

Table 7-9 - Leroux's Angle of Females Lumbar Curves

Surface Angle (θ)	Females Leroux Lumbar Angles			
	$\overline{\gamma}_{(\theta, L1\text{-}L5)}$	$\overline{\lambda}_{(\theta, L1\text{-}L5)}$	$\overline{\gamma}_{(\theta, T12\text{-}L5)}$	$\overline{\lambda}_{(\theta, T12\text{-}L5)}$
-30	31.9 (12.3)	-0.4 (17.7)	35.7 (12.7)	-1.4 (16.4)
-25	30.8 (10.0)	0.7 (15.5)	35.2 (10.0)	-1.1 (13.4)
-20	34.9 (13.1)	-3.4 (16.7)	37.5 (12.5)	-3.3 (15.3)
-15	29.3 (10.2)	2.1 (14.1)	33.0 (10.8)	1.2 (11.9)
-10	28.9 (9.2)	2.5 (14.9)	33.9 (9.2)	0.3 (13.6)
-5	32.0 (9.9)	-0.5 (12.5)	34.4 (10.2)	-0.2 (11.7)
0	31.5 (12.6)	N/A	34.2 (11.2)	N/A
5	28.7 (9.4)	2.8 (15.1)	32.5 (9.9)	1.7 (13.4)
10	32.0 (13.5)	-0.5 (18.7)	35.3 (11.5)	-1.1 (14.8)
15	30.6 (10.8)	0.8 (14.9)	34.1 (11.1)	0.1 (13.4)
20	28.3 (11.3)	3.2 (17.0)	32.2 (12.3)	1.9 (16.0)
25	26.9 (12.2)	4.6 (18.9)	30.6 (12.1)	3.2 (17.2)
30†	21.1 (9.4)	11.0 (17.1)*	26.3 (10.1)	7.9 (16.8)+

† n = 13 for θ = 30°

* - 1% Significance

\+ - 5% Significance

<u>Thoracic and Lumbar</u>

For uphill surfaces the female subjects, like the male subjects, decrease the amount of curvature in both thoracic and lumbar spines as the surface that the subjects stand on becomes more inclined. For downhill surfaces, although there is little change in curvature of the lumbar curve, there is an increase in thoracic curvature when the female subjects stood on steeper downhill surfaces (see Figure 7-2).

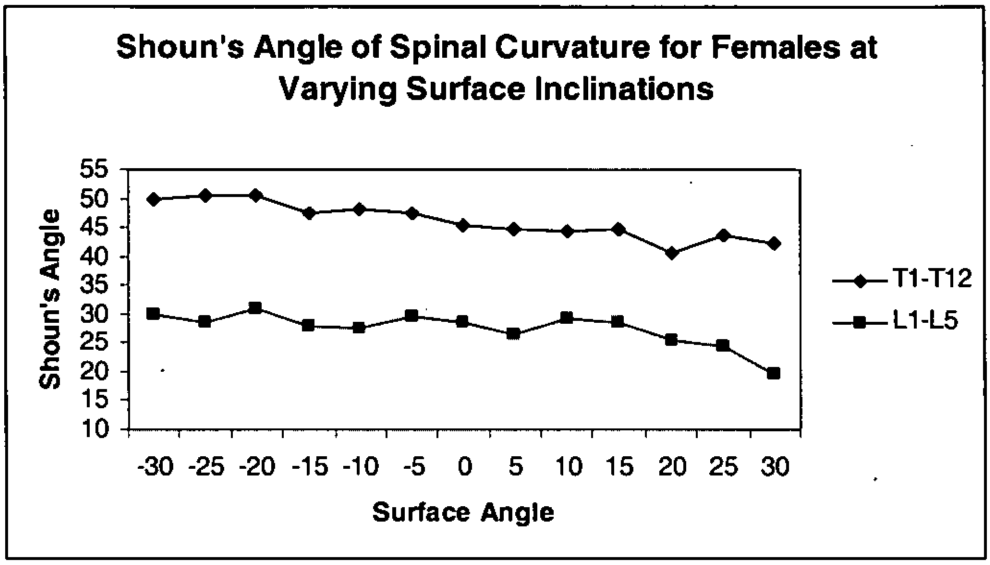

Figure 7-2 - Shoun's Angle of Spinal Curvatures for Females

7.4 Comparison between Males and Females of the Effects of Standing on Different Surface Gradients on the Thoracolumbar Curvatures

<u>Thoracic</u>

The mean female thoracic curvature angle for the T1-T12 range is always greater than the mean male thoracic curvature angle at any of the measured surface gradients. This is significant ($p < 0.05$) on the steeper surface angles of 25°, 30°, -25° and -30° (see Table 7-10 and Table 7-11).

Table 7-10 – Comparison of Male and Female Thoracic Shoun's Angle

Surface Angle (θ)	Female $\overline{\beta}_{(\theta, T1\text{-}T12)}$ – Male $\overline{\beta}_{(\theta, T1\text{-}T12)}$		Female $\overline{\beta}_{(\theta, T1\text{-}L1)}$ – Male $\overline{\beta}_{(\theta, T1\text{-}L1)}$	
	mean	*p*-value	mean	*p*-value
-30	6.0°	0.020	4.7°	0.078
-25	6.3°	0.020	5.6°	0.041
-20	5.2°	0.043	4.3°	0.090
-15	1.5°	0.558	0.7°	0.784
-10	3.2°	0.200	2.3°	0.379
-5	2.6°	0.308	1.8°	0.483
0	0.9°	0.749	-0.1°	0.980
5	2.0°	0.435	1.0°	0.713
10	2.3°	0.370	1.3°	0.619
15	0.6°	0.813	-0.5°	0.863
20	2.1°	0.424	2.2°	0.425
25	7.6°	0.009	6.6°	0.031
30	6.8°	0.040	6.0°	0.073

Table 7-11 - Comparison of Male and Female Thoracic Leroux's Angle

Surface Angle (θ)	Female $\overline{\gamma}_{(\theta, T1\text{-}T12)}$ – Male $\overline{\gamma}_{(\theta, T1\text{-}T12)}$		Female $\overline{\gamma}_{(\theta, T1\text{-}L1)}$ – Male $\overline{\gamma}_{(\theta, T1\text{-}L1)}$	
	mean	*p*-value	mean	*p*-value
-30	5.4°	0.036	4.3°	0.102
-25	6.4°	0.017	5.7°	0.042
-20	3.9°	0.121	3.9°	0.115
-15	1.2°	0.633	0.6°	0.829
-10	2.7°	0.292	2.0°	0.452
-5	2.8°	0.283	1.9°	0.456
0	0.6°	0.814	0.1°	0.973
5	1.4°	0.577	0.3°	0.903
10	2.0°	0.427	1.1°	0.665
15	0.2°	0.932	-0.8°	0.781
20	1.7°	0.504	1.8°	0.526
25	7.4°	0.009	6.4°	0.036
30	6.0°	0.058	4.8°	0.135

Lumbar

The female lumbar curvature angle is always greater than the male lumbar curvature angle for both measurement techniques and both measurement ranges (see Table 7-12 and Table 7-13). For all measurements except $\overline{\beta}_{(30, L1\text{-}L5)}$ and $\overline{\gamma}_{(30, L1\text{-}L5)}$ this is significant ($p < 0.05$) or highly significant ($p < 0.01$).

Table 7-12 - Females - Males Shoun's Angle for Lumbar Spine

Surface Angle (θ)	Female $\overline{\beta}_{(\theta, L1\text{-}L5)}$ – Male $\overline{\beta}_{(\theta, L1\text{-}L5)}$		Female $\overline{\beta}_{(\theta, T12\text{-}L5)}$ – Male $\overline{\beta}_{(\theta, T12\text{-}L5)}$	
	mean	*p*-value	mean	*p*-value
-30	9.3°	<0.001	11.5°	<0.001
-25	6.4°	0.003	9.4°	<0.001
-20	9.3°	<0.001	11.2°	<0.001
-15	6.6°	0.012	10.1°	<0.001
-10	6.2°	0.006	10.2°	<0.001
-5	9.1°	<0.001	12.2°	<0.001
0	7.6°	0.005	10.6°	<0.001
5	6.6°	0.007	10.5°	<0.001
10	9.7°	<0.001	13.7°	<0.001
15	7.0°	0.003	9.8°	<0.001
20	7.3°	0.002	10.2°	<0.001
25	6.0°	0.010	8.0°	0.001
30	3.1°	0.140	5.9°	0.008

Table 7-13 - Females - Males Leroux's Angle for Lumbar Spine

Surface Angle (θ)	Female $\overline{\gamma}_{(\theta, L1\text{-}L5)}$ – Male $\overline{\gamma}_{(\theta, L1\text{-}L5)}$		Female $\overline{\gamma}_{(\theta, T12\text{-}L5)}$ – Male $\overline{\gamma}_{(\theta, T12\text{-}L5)}$	
	mean	*p*-value	mean	*p*-value
-30	9.5°	<0.001	11.9°	<0.001
-25	6.6°	0.004	10.6°	<0.001
-20	11.8°	<0.001	13.0°	<0.001
-15	6.4°	0.013	9.8°	<0.001
-10	5.5°	0.015	10.4°	<0.001
-5	10.0°	<0.001	11.5°	<0.001
0	8.4°	0.004	10.1°	<0.001
5	7.5°	0.002	10.9°	<0.001
10	10.6°	<0.001	13.7°	<0.001
15	7.5°	0.002	9.5°	<0.001
20	8.1°	0.003	10.4°	<0.001
25	6.9°	0.009	8.9°	0.001
30	3.4°	0.121	6.6°	0.004

Thoracic and Lumbar

The female subjects' mean curvature angles are greater than the male subjects' mean curvature angles for both thoracic spine and lumbar spine for most measured surfaces between -30° and 30° (see Figure 7-3 and Figure 7-4). This is in agreement with Vialle *et al* [3] who also found that females had more curvature in thoracic and lumbar spines than males. Vialle *et al* used radiography and Cobb angles to determine the amount of curvature. Lumbar curvature is generally accepted to be higher in females due to the orientation of the female sacrum, which is directed more obliquely backward than the male sacrum [2, 3].

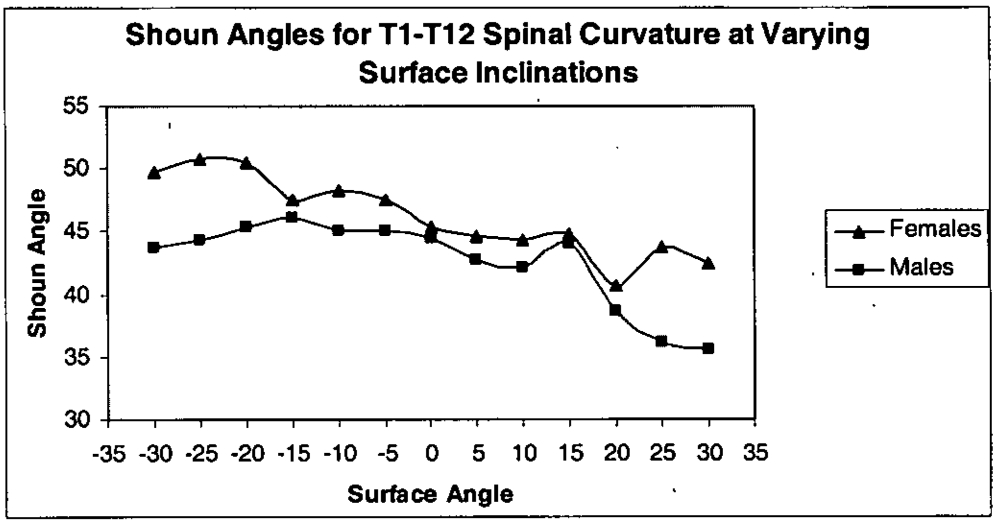

Figure 7-3 - Shoun's T1-T12 Lumbar Angle for Males and Females

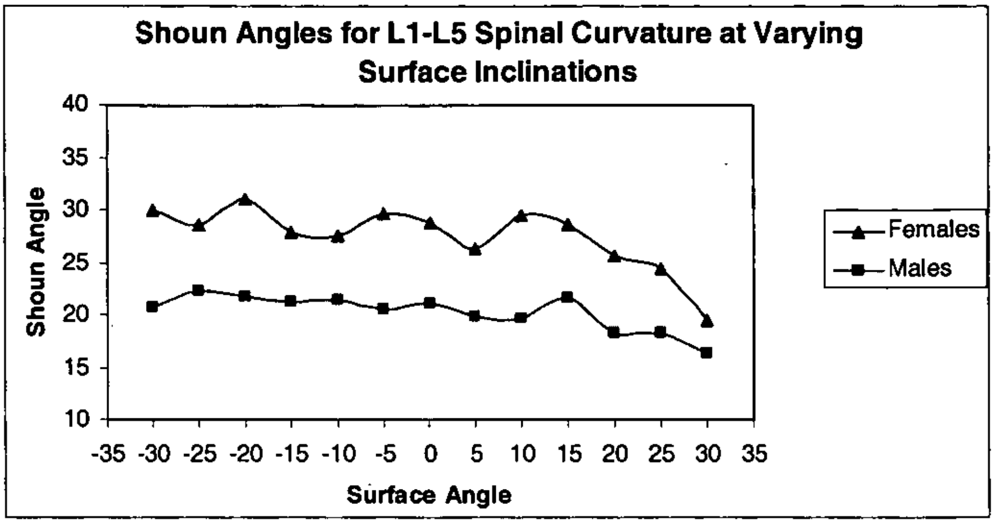

Figure 7-4 - Shoun's L1-L5 Lumbar Angle for Males and Females

7.5 The Effects of Footwear on Thoracic and Lumbar Spinal Curvature of Females

This section describes the changes to the thoracic and lumbar curvatures caused by footwear to female subjects when they stood on different surface gradients. Firstly, the effect of surface gradient on mean thoracic and lumbar curvatures in females wearing small heeled and high heeled shoes is investigated. Secondly, for each surface gradient, one-way ANOVA for repeated measures was used to compare the effect of each pair of shoes on the thoracic and lumbar curvatures.

7.5.1 The Effect of Surface Gradient on Females Wearing Small Heeled Shoes

This section discusses how the female spine is affected by standing on different surface gradients while wearing small heeled shoes.

Thoracic Spine

For females wearing the small heeled shoes, standing on a non-horizontal surface increases the amount of curvature in the thoracic spine regardless of whether it is an uphill surface or a downhill surface. Apart from when $\theta = -30°$, the downhill thoracic curvatures are significantly greater

($p < 0.01$) than the thoracic curvature when standing on horizontal ground for both ranges and both techniques (see Table 7-14, Table 7-15 and Figure 7-5). For uphill surfaces of $\theta = 5°$ and $\theta = 10°$, the T1-L1 thoracic curvatures are significantly greater than when standing on horizontal ground ($p < 0.05$).

Table 7-14 - Shoun Angle for Thoracic Spine of Females Wearing Small Heeled Shoes

Surface Angle (θ)	Females Small Heels Shoun Thoracic Angles			
	$\overline{\beta}_{(sh,\theta,T1\text{-}T12)}$	$\overline{\kappa}_{(sh,\theta,T1\text{-}T12)}$	$\overline{\beta}_{(sh,\theta,T1\text{-}L1)}$	$\overline{\kappa}_{(sh,\theta,T1\text{-}L1)}$
-30†	47.7° (10.0°)	-2.2° (11.7°)	48.8° (9.0°)	-3.5° (10.9°)
-25	51.3° (9.6°)	-4.9° (8.4°)*	52.5° (10.5°)	-5.4° (8.4°)*
-20	51.4° (13.7°)	-5.0° (9.4°)*	52.7° (14.9°)	-5.5° (8.5°)*
-15	50.5° (11.6°)	-4.2° (8.9°)*	52.0° (12.0°)	-4.8° (8.4°)*
-10	51.2° (13.1°)	-4.8° (6.9°)*	52.0° (13.6°)	-4.8° (6.2°)*
-5	49.9° (12.4°)	-3.5° (7.7°)*	51.0° (13.2°)	-3.8° (7.3°)*
0	46.4° (12.6°)	N/A	47.2° (13.6°)	N/A
5	48.6° (10.9°)	-2.2° (8.6°)	50.2° (11.4°)	-3.0° (8.7°)+
10	48.7° (11.3°)	-2.3° (8.4°)	50.1° (11.8°)	-2.9° (8.5°)+
15	46.7° (11.7°)	-0.3° (8.2°)	48.5° (12.2°)	-1.3° (7.5°)
20	48.6° (11.4°)	-2.3° (10.3°)	49.8° (12.3°)	-2.6° (9.9°)
25	47.7° (11.4°)	-1.3° (10.2°)	49.2° (12.4°)	-2.0° (9.4°)
30†	49.1° (11.4°)	-3.6° (9.7°)	48.5° (11.4°)	-3.2° (9.2°)

† n = 11 for θ = -30° and 30°

* - 1% Significance

+ - 5% Significance

Table 7-15 – Leroux Angle for Thoracic Spine of Females Wearing Small Heeled Shoes

Surface Angle (θ)	Females Small Heels Leroux Thoracic Angles			
	$\overline{\gamma}_{(sh,\theta,T1\text{-}T12)}$	$\overline{\lambda}_{(sh,\theta,T1\text{-}T12)}$	$\overline{\gamma}_{(sh,\theta,T1\text{-}L1)}$	$\overline{\lambda}_{(sh,\theta,T1\text{-}L1)}$
-30†	48.3° (9.9°)	-2.1° (12.0°)	49.6° (9.1°)	-3.6° (10.4°)
-25	52.3° (9.4°)	-5.2° (8.9°)*	53.4° (10.3°)	-5.4° (8.3°)*
-20	52.0° (13.9°)	-4.9° (9.8°)*	53.3° (15.0°)	-5.3° (8.7°)*
-15	51.4° (11.5°)	-4.3° (9.1°)*	52.9° (12.0°)	-4.9° (8.1°)*
-10	52.0° (13.3°)	-4.9° (7.2°)*	52.6° (13.7°)	-4.6° (5.9°)*
-5	50.4° (12.6°)	-3.3° (7.6°)+	51.5° (13.2°)	-3.5° (6.9°)*
0	47.1° (12.5°)	N/A	48.0° (13.3°)	N/A
5	49.2° (10.9°)	-2.1° (8.8°)	50.8° (11.4°)	-2.8° (8.3°)+
10	49.5° (11.2°)	-2.4° (8.6°)	50.7° (11.5°)	-2.7° (7.9°)+
15	47.5° (11.4°)	-0.4° (8.2°)	49.2° (12.1°)	-1.2° (7.3°)
20	49.8° (11.3°)	-2.7° (11.0°)	50.7° (12.1°)	-2.6° (9.5°)
25	48.4° (11.5°)	-1.3° (10.4°)	49.8° (12.3°)	-1.8° (9.1°)
30†	49.8° (11.4°)	-3.6° (10.4°)	49.4° (11.2°)	-3.4° (9.5°)

† n = 11 for θ = -30° and 30°

* - 1% Significance

+ - 5% Significance

Lumbar Spine

For lumbar spine curvatures of females wearing small heeled shoes there are no significant differences between standing on any of the surface gradients and the horizontal. Neither is there any clear trend (see Table 7-16 and Table 7-17). Although a majority of the curvatures when standing on the downhill surface gradients are flatter than when standing on a horizontal surface, the differences between means remain insignificant.

Table 7-16 - Shoun's Angle for Females Lumbar Spine in Small Heels

Surface Angle (θ)	Females Small Heels Shoun Lumbar Angles			
	$\overline{\beta}_{(\theta, L1\text{-}L5)}$	$\overline{\kappa}_{(\theta, L1\text{-}L5)}$	$\overline{\beta}_{(\theta, T12\text{-}L5)}$	$\overline{\kappa}_{(\theta, T12\text{-}L5)}$
-30†	26.4° (8.6°)	2.1° (9.6°)	28.6° (10.8°)	3.5° (10.9°)
-25	28.3° (10.5°)	1.6° (12.9°)	30.9° (11.2°)	2.4° (12.5°)
-20	28.5° (10.4°)	1.4° (10.4°)	32.6° (10.9°)	0.6° (10.1°)
-15	27.8° (11.1°)	2.1° (11.3°)	32.2° (11.0°)	1.0° (10.8°)
-10	31.2° (11.6°)	-1.3° (11.5°)	35.2° (10.9°)	-1.9° (10.8°)
-5	27.4° (10.2°)	2.4° (9.6°)	31.0° (11.2°)	2.3° (10.6°)
0	29.9° (9.8°)	N/A	33.3° (10.4°)	N/A
5	28.3° (9.1°)	1.6° (9.4°)	32.4° (9.5°)	0.9° (9.6°)
10	27.9° (8.7°)	1.9° (9.3°)	31.6° (9.1°)	1.7° (8.7°)
15	29.6° (10.5°)	0.3° (11.5°)	33.4° (10.6°)	-0.2° (10.0°)
20	31.2° (11.2°)	-1.3° (12.2°)	34.5° (11.6°)	-1.2° (11.2°)
25	28.0° (10.0°)	1.9° (11.1°)	32.1° (10.3°)	1.2° (11.5°)
30†	30.1° (8.5°)	-1.7° (10.6°)	33.8° (10.1°)	-1.7° (9.2°)

† n = 11 for θ = -30° and 30°

* - 1% Significance

+ - 5% Significance

Table 7-17 - Leroux's Angle for Females Lumbar Spine in Small Heels

Surface Angle (θ)	Females Small Heels Leroux Lumbar Angles			
	$\overline{\gamma}_{(\theta, L1\text{-}L5)}$	$\overline{\lambda}_{(\theta, L1\text{-}L5)}$	$\overline{\gamma}_{(\theta, T12\text{-}L5)}$	$\overline{\lambda}_{(\theta, T12\text{-}L5)}$
-30†	27.9° (8.3°)	1.7° (10.4°)	30.2° (9.9°)	2.8° (9.9°)
-25	31.1° (11.7°)	0.2° (14.7°)	33.6° (11.6°)	0.5° (13.4°)
-20	30.5° (10.4°)	0.8° (11.5°)	33.8° (10.6°)	0.3° (10.4°)
-15	30.1° (11.7°)	1.1° (13.0°)	34.7° (11.2°)	-0.7° (11.5°)
-10	34.1° (13.4°)	-2.8° (13.8°)	38.1° (13.8°)	-4.0° (12.7°)
-5	30.7° (11.1°)	0.6° (11.6°)	33.6° (11.4°)	0.5° (11.1°)
0	31.2° (9.9°)	N/A	34.1° (10.6°)	N/A
5	30.8° (9.3°)	0.5° (10.3°)	34.2° (10.0°)	-0.1° (10.0°)
10	30.2° (9.4°)	1.1° (10.3°)	33.0° (9.6°)	1.1° (9.5°)
15	31.2° (11.0°)	0.0° (12.3°)	35.6° (10.6°)	-1.5° (10.2°)
20	33.8° (12.8°)	-2.5° (14.4°)	36.6° (12.4°)	-2.5° (12.2°)
25	30.2° (11.3°)	1.0° (12.4°)	34.5° (10.8°)	-0.4° (12.1°)
30†	33.9° (10.8°)	-4.4° (12.9°)	37.2° (11.6°)	-4.2° (11.1°)

† n = 11 for θ = -30° and 30°

* - 1% Significance

+ - 5% Significance

For both of the measurement techniques and both of the measurement ranges the change in curvature follows no clear trend (see Figure 7-5) even though there are some significant differences.

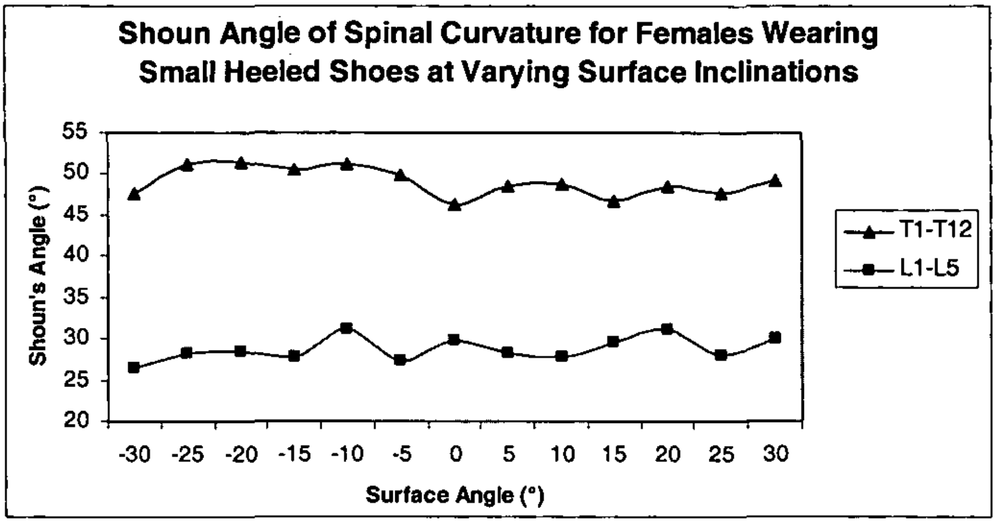

Figure 7-5 - Shoun's Angle of Spinal Curvature for Females Wearing Small Heeled Shoes

7.5.2 The Effect of Surface Gradient on Females Wearing High Heeled Shoes

This section discusses how the female spine is affected by standing on different surface gradients while wearing high heeled shoes.

Thoracic

The effect of surface gradient on the female subjects wearing the high heeled shoes was similar to the effect of surface gradient on the female subjects wearing the small heeled shoes. Regardless of heel height, the thoracic curvature generally increases on both uphill and downhill surfaces (see Table 7-18 and Table 7-19).

Table 7-18 - Shoun's Angle for Females Thoracic Spine in High Heels

Surface Angle (θ)	Females High Heels Shoun Thoracic Angles			
	$\overline{\beta}_{(\theta, T1\text{-}T12)}$	$\overline{\kappa}_{(\theta, T1\text{-}T12)}$	$\overline{\beta}_{(\theta, T1\text{-}L1)}$	$\overline{\kappa}_{(\theta, T1\text{-}L1)}$
-30‡	46.8° (4.7°)	-3.9° (9.4°)	49.7° (3.7°)	-4.2° (10.7°)
-25#	48.7° (13.3°)	-2.1° (13.9°)	50.6° (14.3°)	-2.4° (12.9°)
-20^	48.9° (12.1°)	-3.9° (10.0°)+	51.2° (12.3°)	-4.4° (9.5°)+
-15	50.6° (13.1°)	-4.0° (8.5°)*	52.4° (13.5°)	-3.9° (7.5°)*
-10	48.3° (13.2°)	-2.1° (8.4°)	49.8° (13.9°)	-1.7° (8.6°)
-5	48.2° (11.7°)	-2.0° (8.0°)	50.5° (11.9°)	-2.4° (7.3°)
0	46.2° (13.3°)	N/A	48.1° (13.8°)	N/A
5	48.6° (12.8°)	-2.4° (6.8°)+	50.0° (12.8°)	-2.0° (6.2°)
10	47.1° (13.5°)	-0.9° (9.8°)	48.6° (13.7°)	-0.5° (9.0°)
15	48.7° (11.5°)	-2.5° (8.6°)	49.7° (11.6°)	-1.6° (7.6°)
20^	49.5° (11.7°)	-4.4° (9.4°)+	50.1° (11.9°)	-3.3° (8.9°)+
25#	50.3° (11.6°)	-3.8° (6.8°)*	51.2° (12.3°)	-2.9° (6.5°)+
30†	43.5° (9.3°)	-2.7° (8.3°)	45.0° (8.7°)	-1.7° (8.6°)

‡ n = 4 for θ = -30°

\# n = 15 for θ = -25° and 25°

^ n = 17 for θ = -20° and 20°

† n = 5 for θ = 30°

* - 1% Significance

\+ - 5% Significance

However, unlike the effect of surface gradient on females wearing small heeled shoes results, the effect of surface gradient on females wearing high heeled shoes is much less and is only significant between the horizontal and the surface gradients of -20°, -15°, 20° and 25° ($p < 0.05$).

Table 7-19 - Leroux's Angle for Females Thoracic Spine in High Heels

Surface Angle (θ)	Females High Heels Leroux Thoracic Angles			
	$\overline{\gamma}_{(\theta, T1\text{-}T12)}$	$\overline{\lambda}_{(\theta, T1\text{-}T12)}$	$\overline{\gamma}_{(\theta, T1\text{-}L1)}$	$\overline{\lambda}_{(\theta, T1\text{-}L1)}$
-30‡	47.4° (5.1°)	-4.1° (8.5°)	51.5° (3.8°)	-5.0° (12.0°)
-25#	49.5° (13.6°)	-2.1° (14.5°)	51.0° (14.3°)	-1.8° (13.0°)
-20^	50.6° (12.2°)	-4.9° (11.0°)+	52.7° (11.7°)	-4.9° (9.9°)*
-15	51.5° (13.4°)	-4.2° (8.4°)*	53.3° (13.4°)	-3.8° (7.8°)*
-10	49.1° (13.3°)	-2.2° (8.6°)	50.9° (14.1°)	-1.9° (8.9°)
-5	49.0° (11.8°)	-2.1° (8.1°)	51.2° (12.0°)	-2.2° (7.5°)
0	46.9° (13.4°)	N/A	49.0° (13.8°)	N/A
5	49.6° (13.0°)	-2.7° (7.4°)+	50.9° (12.9°)	-1.9° (6.8°)
10	47.8° (13.4°)	-0.9° (9.9°)	49.8° (13.6°)	-0.8° (9.4°)
15	49.8° (11.7°)	-2.9° (9.2°)	50.5° (11.7°)	-1.5° (7.9°)
20^	50.1° (11.8°)	-4.3° (9.5°)+	50.8° (12.1°)	-3.1° (8.8°)+
25#	51.2° (11.3°)	-3.9° (7.3°)*	52.5° (11.9°)	-3.3° (6.8°)+
30†	44.2° (9.4°)	-3.0° (8.7°)	45.8° (8.4°)	-1.6° (9.0°)

‡ n = 4 for θ = -30°

\# n = 15 for θ = -25° and 25°

^ n = 17 for θ = -20° and 20°

† n = 5 for θ = 30°

* - 1% Significance

+ - 5% Significance

Lumbar

Standing on non-horizontal surfaces, regardless of whether that surface is downhill or uphill causes an increase in the lumbar curvature angle. This increase is significant at surface gradients of -5° and between 10° and 25° inclusive; although, not necessarily across both ranges and both measurement techniques (see Table 7-20 and Table 7-21).

Table 7-20 - Shoun's Angle for Females Lumbar Spine in High Heels

Surface Angle (θ)	Females High Heels Shoun Lumbar Angles			
	$\overline{\beta}_{(\theta, L1\text{-}L5)}$	$\overline{\kappa}_{(\theta, L1\text{-}L5)}$	$\overline{\beta}_{(\theta, T12\text{-}L5)}$	$\overline{\kappa}_{(\theta, T12\text{-}L5)}$
-30‡	33.2° (10.1°)	-7.7° (10.9°)	36.2° (14.2°)	-6.5° (13.0°)
-25#	24.9° (11.9°)	-0.5° (12.8°)	28.2° (12.8°)	0.1° (11.2°)
-20^	24.0° (9.6°)	-0.7° (10.7°)	28.0° (9.8°)	-0.2° (8.9°)
-15	27.0° (10.8°)	-3.0° (12.1°)	30.9° (10.7°)	-2.1° (10.4°)
-10	27.0° (11.1°)	-3.0° (11.9°)	30.9° (11.0°)	-2.1° (11.0°)
-5	28.1° (10.2°)	-4.1° (10.3°)+	32.2° (10.5°)	-3.4° (9.8°)+
0	24.0° (9.2°)	N/A	28.7° (8.6°)	N/A
5	26.4° (11.0°)	-2.4° (9.0°)	29.8° (11.1°)	-1.1° (8.2°)
10	27.6° (9.7°)	-3.6° (11.2°)	31.2° (10.4°)	-2.5° (10.2°)
15	31.7° (11.3°)	-7.7° (12.6°)*	35.4° (11.2°)	-6.7° (11.5°)*
20^	28.3° (8.7°)	-5.1° (8.0°)*	32.2° (9.1°)	-4.3° (7.5°)*
25#	29.0° (10.8°)	-4.6° (10.7°)+	31.9° (12.0°)	-3.6° (11.0°)
30†	32.4° (17.8°)	-9.2° (17.2°)	36.3° (18.8°)	-8.5° (17.4°)

‡ $n = 4$ for $\theta = -30°$

$n = 15$ for $\theta = -25°$ and $25°$

^ $n = 17$ for $\theta = -20°$ and $20°$

† $n = 5$ for $\theta = 30°$

* - 1% Significance

+ - 5% Significance

Table 7-21 - Leroux's Angle for Females Lumbar Spine in High Heels

Surface Angle (θ)	Females High Heels Leroux Lumbar Angles			
	$\overline{\gamma}_{(\theta, L1\text{-}L5)}$	$\overline{\lambda}_{(\theta, L1\text{-}L5)}$	$\overline{\gamma}_{(\theta, T12\text{-}L5)}$	$\overline{\lambda}_{(\theta, T12\text{-}L5)}$
-30‡	34.8° (9.0°)	-7.6° (11.5°)	37.9° (13.4°)	-4.7° (13.2°)
-25#	26.8° (13.1°)	-0.3° (15.3°)	29.5° (12.9°)	1.0° (12.0°)
-20^	25.8° (10.9°)	-0.6° (12.1°)	31.0° (10.8°)	-0.9° (10.8°)
-15	29.0° (11.8°)	-2.8° (13.8°)	32.4° (10.6°)	-1.3° (11.0°)
-10	29.1° (11.6°)	-3.1° (12.8°)	33.0° (11.2°)	-2.1° (12.0°)
-5	29.6° (10.3°)	-3.5° (11.0°)	34.7° (9.7°)	-3.8° (9.5°)+
0	26.1° (10.2°)	N/A	30.9° (9.4°)	N/A
5	29.9° (13.8°)	-3.8° (12.6°)	33.1° (13.8°)	-2.2° (11.8°)
10	31.5° (12.1°)	-5.4° (15.0°)+	33.7° (11.4°)	-2.8° (12.2°)
15	34.5° (12.8°)	-8.4° (13.9°)*	38.0° (13.6°)	-7.1° (15.4°)*
20^	30.6° (9.7°)	-5.2° (9.5°)*	34.5° (10.0°)	-4.4° (8.8°)*
25#	31.8° (12.6°)	-5.3° (13.3°)+	34.5° (12.3°)	-4.0° (11.0°)
30†	34.5° (17.1°)	-9.4° (17.0°)	38.2° (18.4°)	-7.2° (17.1°)

‡ n = 4 for θ = -30°
# n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 5 for θ = 30°
* - 1% Significance
+ - 5% Significance

Looking at Figure 7-6 it can be seen that the effects show no trend for either the thoracic or lumbar curvatures. These results are very different from the results for barefoot females. Like the results of the small heels comparison, the curvature on horizontal ground has the smallest curvature and there is little observed trend.

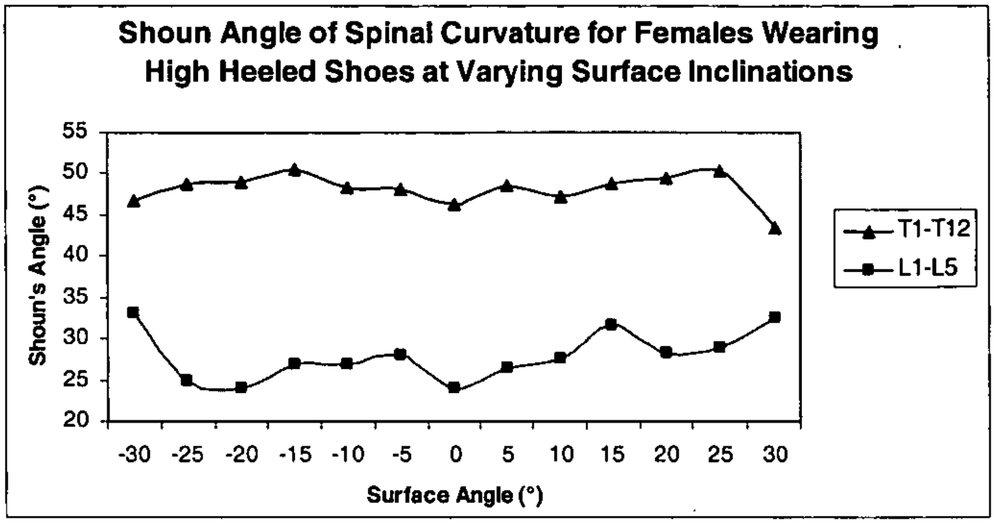

Figure 7-6 - Shoun's Angle of Spinal Curvature for Females Wearing High Heeled Shoes

7.5.3 The Effect of Footwear on Females Standing on Different Surface Gradients

This section discusses the effects of footwear on the thoracic and lumbar curvatures of females stood on different surface gradients.

<u>Thoracic</u>

For all of the inclined surfaces, wearing shoes with heels increases the amount of curvature in the thoracic spine (see Table 7-22, Table 7-23, Table 7-24, Table 7-25 and Figure 7-7).

For both the T1-T12 and the T1-L1 ranges and for both measurement techniques, on a majority of the uphill surfaces, wearing small heeled shoes causes a significant increase in thoracic curvature ($p < 0.05$). The only measurements where this was not significant are:

$\overline{\kappa}_{(15, T1\text{-}T12)} - \overline{\kappa}_{(sh, 15, T1\text{-}T12)}$, $\overline{\lambda}_{(10, T1\text{-}T12)} - \overline{\lambda}_{(sh, 10, T1\text{-}T12)}$,

$\overline{\lambda}_{(15, T1\text{-}T12)} - \overline{\lambda}_{(sh, 15, T1\text{-}T12)}$ and $\overline{\lambda}_{(15, T1\text{-}L1)} - \overline{\lambda}_{(sh, 15, T1\text{-}L1)}$.

For the horizontal and downhill surfaces, there are no significant differences in thoracic curvature between wearing small heels and being barefoot for any of the surfaces, using either of the measurement techniques or either of the measurement ranges ($p < 0.05$).

Table 7-22 – Pairwise Comparison of Female T1-T12 Shoun Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{\kappa}_{(\theta, T1\text{-}T12)} - \overline{\kappa}_{(sh, \theta, T1\text{-}T12)}$		$\overline{\kappa}_{(\theta, T1\text{-}T12)} - \overline{\kappa}_{(hh, \theta, T1\text{-}T12)}$		$\overline{\kappa}_{(sh, \theta, T1\text{-}T12)} - \overline{\kappa}_{(hh, \theta, T1\text{-}T12)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30[*]	-1.7	NS	-2.4	NS	-0.7	NS
-25[+]	0.1	NS	3.1	NS	3.0	NS
-20[^]	-0.6	NS	1.6	NS	2.2	NS
-15	-3.1	NS	-2.5	NS	0.5	NS
-10	-2.9	NS	0.0	NS	2.9	NS
-5	-2.5	NS	-0.7	NS	1.8	NS
0	-1.9	NS	-1.4	NS	0.5	NS
5	-3.9	0.007	-3.8	0.010	0.2	NS
10	-4.3	0.002	-2.7	NS	1.6	NS
15	-2.0	NS	-3.7	0.005	-1.6	NS
20[^]	-7.3	0.001	-8.7	<0.001	-1.4	NS
25[+]	-3.9	0.013	-6.7	0.002	-2.9	NS
30[†]	-12.0	0.042	-16.6	0.036	-4.6	NS

[*] n = 4 for θ = -30°
[+] n = 15 for θ = -25° and 25°
[^] n = 17 for θ = -20° and 20°
[†] n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

Similarly, for both the T1-T12 and the T1-L1 ranges and for both measurement techniques, on all uphill surfaces except 10°, wearing high heeled shoes causes a significant increase in thoracic curvature ($p < 0.05$). For the horizontal and downhill surfaces, there are no significant differences in thoracic curvature between wearing small heels and being barefoot for any of the surfaces, using either of the measurement techniques or either of the measurement ranges.

The thoracic curvature is not significantly affected by heel height as there are no significant differences on any of the surfaces, using either of the measurement techniques or either of the measurement ranges between wearing the two pairs of heeled shoes ($p < 0.05$).

Table 7-23 - Pairwise Comparison of Female T1-L1 Shoun Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{K}_{(\theta, T1\text{-}L1)} - \overline{K}_{(sh, \theta, T1\text{-}L1)}$		$\overline{K}_{(\theta, T1\text{-}L1)} - \overline{K}_{(hh, \theta, T1\text{-}L1)}$		$\overline{K}_{(sh, \theta, T1\text{-}L1)} - \overline{K}_{(hh, \theta, T1\text{-}L1)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	-1.6	NS	-2.8	NS	-1.2	NS
-25+	0.7	NS	3.0	NS	2.3	NS
-20^	0.0	NS	1.3	NS	1.3	NS
-15	-2.6	NS	-2.2	NS	0.4	NS
-10	-1.8	NS	0.6	NS	2.4	NS
-5	-2.1	NS	-1.2	NS	0.8	NS
0	-0.9	NS	-1.2	NS	-0.3	NS
5	-3.9	0.003	-3.4	0.019	0.6	NS
10	-4.3	0.003	-2.6	NS	1.7	NS
15	-2.6	0.043	-3.3	0.009	-0.6	NS
20^	-6.9	0.002	-7.7	<0.001	-0.9	NS
25+	-4.4	0.006	-6.5	0.004	-2.1	NS
30†	-11.3	0.044	-16.9	0.023	-5.6	NS

* n = 4 for θ = -30°
+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

Table 7-24 - Pairwise Comparison of Female T1-T12 Leroux Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{\lambda}_{(\theta,\,T1\text{-}T12)} - \overline{\lambda}_{(sh,\,\theta,\,T1\text{-}T12)}$		$\overline{\lambda}_{(\theta,\,T1\text{-}T12)} - \overline{\lambda}_{(hh,\,\theta,\,T1\text{-}T12)}$		$\overline{\lambda}_{(sh,\,\theta,\,T1\text{-}T12)} - \overline{\lambda}_{(hh,\,\theta,\,T1\text{-}T12)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	-2.3	NS	-2.9	NS	-0.7	NS
-25+	-0.1	NS	3.0	NS	3.1	NS
-20^	-0.7	NS	0.6	NS	1.3	NS
-15	-3.2	NS	-2.7	NS	0.5	NS
-10	-3.1	NS	-0.1	NS	3.0	NS
-5	-2.1	NS	-0.6	NS	1.5	NS
0	-1.4	NS	-0.9	NS	0.5	NS
5	-3.7	0.010	-3.9	0.008	-0.2	NS
10	-4.3	NS	-2.5	NS	1.8	NS
15	-2.0	NS	-3.9	0.007	-1.9	NS
20^	-7.7	0.001	-8.5	<0.001	-0.9	NS
25+	-4.0	0.014	-7.0	0.002	-3.0	NS
30†	-12.4	0.028	-17.2	0.035	-4.8	NS

* n = 4 for θ = -30°
\+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

Table 7-25 – Pairwise Comparison of Female T1-L1 Leroux Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{\lambda}_{(\theta, T1-L1)} - \overline{\lambda}_{(sh, \theta, T1-L1)}$		$\overline{\lambda}_{(\theta, T1-L1)} - \overline{\lambda}_{(hh, \theta, T1-L1)}$		$\overline{\lambda}_{(sh, \theta, T1-L1)} - \overline{\lambda}_{(hh, \theta, T1-L1)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	-1.5	NS	-4.2	NS	-2.7	NS
-25+	0.6	NS	3.4	NS	2.8	NS
-20^	0.2	NS	0.7	NS	0.4	NS
-15	-2.8	NS	-2.4	NS	0.4	NS
-10	-1.9	NS	0.0	NS	1.9	NS
-5	-1.5	NS	-0.9	NS	0.6	NS
0	-0.7	NS	-1.2	NS	-0.5	NS
5	-3.8	0.004	-3.6	0.014	0.2	NS
10	-4.0	0.006	-2.9	NS	1.1	NS
15	-2.5	0.056	-3.3	0.009	-0.8	NS
20^	-7.0	0.002	-7.8	<0.001	-0.8	NS
25+	-4.2	0.015	-6.9	0.003	-2.7	NS
30†	-11.5	0.047	-17.4	0.019	-5.9	NS

* n = 4 for θ = -30°
+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

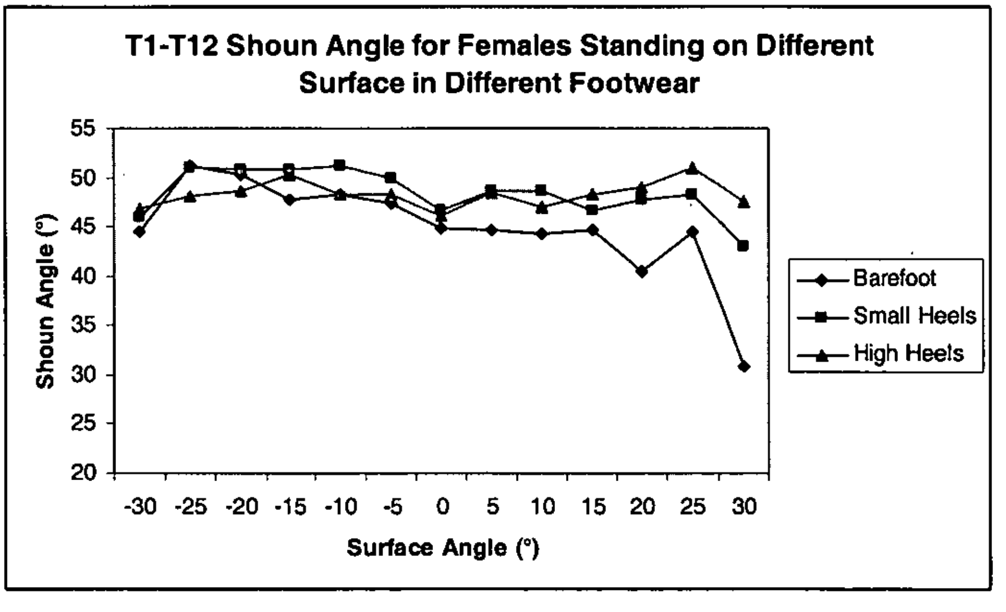

Figure 7-7 – T1-T12 Shoun Angle for Females Wearing Different Footwear

Lumbar

For most of the inclined surfaces, wearing shoes with heels increases the amount of curvature in the lumbar spine. For most of the downhill surfaces, wearing heeled shoes decreases the amount of curvature in the lumbar spine. However this is rarely significant ($p < 0.05$). Steeper uphill surfaces generally resulted in a larger differences caused by footwear (see Table 7-26, Table 7-27, Table 7-28, Table 7-29 and Figure 7-8).

The difference between wearing the small heeled shoes and being barefoot on downhill surfaces is not significant for any of the measured downhill surfaces. There were significant increases in the lumbar curve between wearing the small heeled shoes and being barefoot on uphill surfaces of 20° (Shoun L1-L5) and 25° (Leroux T12-L5) for $p < 0.05$.

Table 7-26 - Pairwise Comparison of Female L1-L5 Shoun Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{K}_{(\theta, L1\text{-}L5)} - \overline{K}_{(sh, \theta, L1\text{-}L5)}$		$\overline{K}_{(\theta, L1\text{-}L5)} - \overline{K}_{(hh, \theta, L1\text{-}L5)}$		$\overline{K}_{(sh, \theta, L1\text{-}L5)} - \overline{K}_{(hh, \theta, L1\text{-}L5)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	0.4	NS	-1.3	NS	-1.7	NS
-25+	0.1	NS	3.2	NS	3.0	NS
-20^	1.7	NS	5.7	0.003	4.0	0.049
-15	0.5	NS	0.4	NS	-0.1	NS
-10	-3.6	NS	-0.2	NS	3.4	NS
-5	3.3	NS	1.4	NS	-1.9	NS
0	-0.2	NS	4.9	0.007	5.0	0.003
5	-1.9	NS	-0.4	NS	1.5	NS
10	1.5	NS	1.6	NS	0.1	NS
15	-1.0	NS	-2.7	NS	-1.8	NS
20^	-4.7	0.024	-3.5	NS	1.2	NS
25+	-4.4	NS	-7.3	0.013	-2.8	NS
30†	-8.6	NS	0.1	NS	8.7	NS

* n = 4 for θ = -30°
+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

The difference in lumbar curvature between wearing the high heeled shoes and being barefoot on downhill surfaces is significant for -20° (both techniques, both measurement ranges) and -25° (Leroux T12-L5) where $p < 0.05$. There were significant increases in the lumbar curve between wearing the small heeled shoes and being barefoot on the 20° surface (both techniques, both measurement ranges) where $p < 0.05$. Notably, for the L1-L5 range, when standing on the horizontal, the female subjects showed a significant reduction in lumbar curvature when they wore the high heeled shoes ($p < 0.05$).

Table 7-27 - Pairwise Comparison of Female T12-L5 Shoun Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{K}_{(\theta, T12\text{-}L5)} - \overline{K}_{(sh, \theta, T12\text{-}L5)}$		$\overline{K}_{(\theta, T12\text{-}L5)} - \overline{K}_{(hh, \theta, T12\text{-}L5)}$		$\overline{K}_{(sh, \theta, T12\text{-}L5)} - \overline{K}_{(hh, \theta, T12\text{-}L5)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	1.0	NS	-0.4	NS	-1.4	NS
-25+	2.1	NS	3.8	NS	1.8	NS
-20^	1.4	NS	5.2	0.003	3.8	0.051
-15	0.1	NS	0.7	NS	0.6	NS
-10	-2.9	NS	0.8	NS	3.7	NS
-5	3.2	NS	0.8	NS	-2.4	NS
0	-0.3	NS	3.4	NS	3.7	0.010
5	-1.4	NS	0.7	NS	2.1	NS
10	2.1	NS	2.1	NS	0.1	NS
15	-0.9	NS	-2.7	NS	-1.8	NS
20^	-3.6	NS	-3.1	NS	0.5	NS
25+	-4.2	NS	-6.5	0.021	-2.2	NS
30†	-8.2	NS	-1.0	NS	7.2	NS

* n = 4 for θ = -30°
+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

Higher heels reduces the lumbar curvature on the horizontal (both Shoun ranges and Leroux L1-L5) where $p < 0.05$. High heels also reduces the lumbar curvature on the -20° surface (both Shoun ranges) where $p < 0.052$.

Table 7-28 - Pairwise Comparison of Female L1-L5 Leroux Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{\lambda}_{(\theta, L1\text{-}L5)} - \overline{\lambda}_{(sh, \theta, L1\text{-}L5)}$		$\overline{\lambda}_{(\theta, L1\text{-}L5)} - \overline{\lambda}_{(hh, \theta, L1\text{-}L5)}$		$\overline{\lambda}_{(sh, \theta, L1\text{-}L5)} - \overline{\lambda}_{(hh, \theta, L1\text{-}L5)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	0.5	NS	-1.8	NS	-2.3	NS
-25+	0.0	NS	3.6	NS	3.6	NS
-20^	3.5	NS	7.5	0.003	4.0	NS
-15	-0.3	NS	-0.1	NS	0.3	NS
-10	-5.1	NS	-1.2	NS	4.0	NS
-5	2.8	NS	2.5	NS	-0.3	NS
0	1.2	NS	5.6	0.012	4.4	0.024
5	-2.1	NS	-1.7	NS	0.4	NS
10	1.8	NS	0.5	NS	-1.4	NS
15	-0.6	NS	-3.4	NS	-2.8	NS
20^	-4.7	NS	-3.0	NS	1.8	NS
25+	-4.7	NS	-7.9	0.013	-3.2	NS
30†	-7.0	NS	2.3	NS	9.3	NS

* n = 4 for θ = -30°
+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

Table 7-29 - Pairwise Comparison of Female T12-L5 Leroux Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{\lambda}_{(\theta, T12\text{-}L5)} - \overline{\lambda}_{(sh, \theta, T12\text{-}L5)}$		$\overline{\lambda}_{(\theta, T12\text{-}L5)} - \overline{\lambda}_{(hh, \theta, T12\text{-}L5)}$		$\overline{\lambda}_{(sh, \theta, T12\text{-}L5)} - \overline{\lambda}_{(hh, \theta, T12\text{-}L5)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	2.5	NS	0.3	NS	-2.2	NS
-25+	1.7	NS	4.9	0.020	3.2	NS
-20^	2.9	NS	5.1	0.037	2.2	NS
-15	-1.3	NS	0.1	NS	1.4	NS
-10	-4.2	NS	0.3	NS	4.5	NS
-5	1.8	NS	-0.4	NS	-2.3	NS
0	1.0	NS	3.4	NS	2.4	NS
5	-1.7	NS	-0.9	NS	0.8	NS
10	2.3	NS	1.4	NS	-0.9	NS
15	-1.5	NS	-3.7	NS	-2.2	NS
20^	-3.6	NS	-3.1	NS	0.4	NS
25+	-5.4	0.034	-7.4	0.009	-2.0	NS
30†	-9.0	NS	-0.2	NS	8.7	NS

* n = 4 for θ = -30°
\+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°

NS - Not Significant
Sig. – Significance

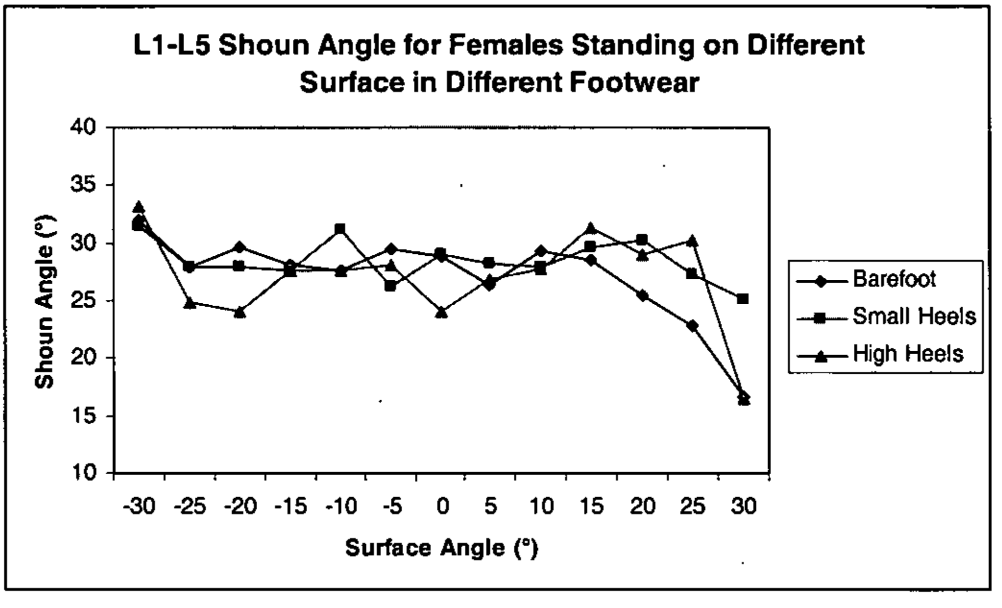

Figure 7-8 – L1-L5 Shoun Angle for Females Wearing Different Footwear

7.6 Conclusions

The analysis undertaken in this chapter suggests that both footwear and surface gradient can significantly affect both the thoracic and lumbar curvatures.

The analysis in Chapter 6 demonstrated that steep uphill surface gradients (> 15°) caused both male and female subjects to lean further forward. Additional to that, it can be seen that those subjects also had significantly flatter thoracic and lumbar spines when on the same steep uphill surfaces than when standing on horizontal ground.

On the downhill surfaces, the male subjects did not significantly alter their thoracic or lumbar spinal curvatures on any of the surfaces, considering that the male subjects also did not have any significant changes in thoracolumbar offset, it appears as though the male spine is not affected by standing on downhill surfaces up to -30°.

When the female subjects stood on the downhill surfaces they assumed a more curved thoracic curvature, this was significant on surfaces ≤ -20°. The female subjects' lumbar spine did not show any general or significant changes when stood on any of the downhill surfaces.

The female thoracic and lumbar curvatures are greater than the male curvatures for all measured surface angles. For the thoracic spine this is significant at the steepest uphill (≥ 25°) and downhill surfaces (≤ -25°). For the lumbar curvature this is significant for all measured surfaces.

Females wearing the small heeled shoes on a non-horizontal surface had a larger thoracic curvature than when they stood on the horizontal in the small heeled shoes. This increase was significant for $-25 \leq \theta \leq -5°$. Lumbar curvature did not appear to be affected.

Similarly, females wearing the high heeled shoes on a non-horizontal surface had a larger thoracic curvature than when they stood on the horizontal surface in the high heeled shoes. However this increase was only significant for $\theta = -20$, -15°, 20° and 25°. Unlike when wearing the small heels, the lumbar curvature of females wearing high heeled shoes was greater when standing on non-horizontal surfaces compared to when standing on the horizontal. This increase was significant at surface gradients of -5° and 15°, 20° and 25°.

Wearing heeled shoes rather than being barefoot on most inclined surfaces significantly increased the thoracic curvature of the female subjects. Wearing heels on the horizontal surface and on the downhill surfaces did not cause any significant changes to thoracic curvature. Thoracic curvature does not appear to be affected by heel height.

Wearing heeled shoes rather than being barefoot on most inclined surfaces increased the lumbar curvature of the female subjects but rarely is it significant. Wearing heels on the downhill surfaces generally caused a reduction in lumbar curvature, although significant differences were rare. The most notable observation for the effects of heeled shoes on lumbar curvature is that on horizontal ground, wearing high heels significantly reduced lumbar curvature while the small heeled shoes did not significantly reduce it. Therefore, on horizontal ground the height of the heel makes a difference. This may support claims of lower back pain developing in cases of wearing high heeled shoes. There was no relationship between heel height and surface gradient, i.e. wearing heeled footwear and standing on declined surfaces are not similar in terms of the postural changes that occur. Given that for each person, balance can be achieved in many different ways the differences in posture could be due to the familiarity that the female subjects had with the footwear while they would have been less familiar with the downhill surface.

Chapter 8 - Sacrum Angle

This chapter focuses on the sacrum angle and how it is affected by the changes in the surface gradient that a person is standing on and changes of the footwear that a person is wearing.

8.1 Methodology and Definitions

The sacrum angle for this study is defined to be the anticlockwise angle (α) that the sacrum makes with the vertical as measured by the SpinalMouse® (see Figure 8-1). Changes in the sacrum angle generally have a significant impact upon the thoracolumbar offset and lumbar lordosis [3].

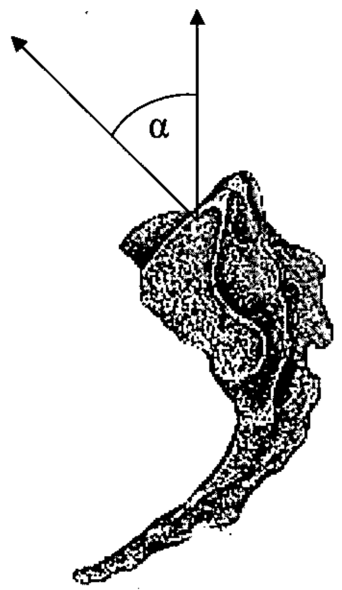

Figure 8-1 - Sacrum Angle
(Image adapted from Gray's Anatomy [2])

The following statistical analyses were completed:

- Paired *t*-tests to determine whether surface gradient had an effect on the male sacrum angle.
- Paired *t*-tests to determine whether surface gradient had an effect on the female sacrum angle.
- Independent two-sample *t*-tests of the difference between mean male and female sacrum angle at each surface angle.
- Paired *t*-tests to determine whether surface gradient had an effect on the female sacrum angle when the subjects wore heeled shoes.
- One-way ANOVA for repeated measures was used to compare the effect of each pair of shoes on the sacrum angle at each surface angle.

Analysis was performed using SPSS® software to calculate Student's *t*-tests. For the independent *t*-tests a Levene's test p-value of 0.05 was taken to mean equal variances could not be assumed and the unequal variances method of *t*-tests was used.

For ANOVA analysis, Mauchly's test of sphericity was used to determine sphericity (equality of the variances between groups). If Mauchly's test was significant i.e. sphericity could not be assumed, the significance level of the Lower-bound test was used to determine whether the null hypothesis could be rejected.

Notations

The following notations are used throughout this chapter.

- θ is defined to be the angle of the surface to the horizontal (where $-30° \leq \theta \leq 30°$). Negative values of θ represent a downhill surface, while positive values represent an uphill surface.

- $\overline{\alpha}_{\theta}$ is used to represent the mean sacrum angle at a surface angle of θ standing barefoot. For example, the mean sacrum angle when standing on a surface inclined at 10° is represented by $\overline{\alpha}_{10}$. Larger values of $\overline{\alpha}_{\theta}$ indicate that the pelvis is rotating forward.

- $\overline{\tau}_{\theta}$ is used for the difference between $\overline{\alpha}_{\theta}$ and $\overline{\alpha}_{0}$. That is, the difference between the sacrum angle when standing on a surface inclined at θ and the sacrum angle when standing on a surface inclined at 0° (i.e. $\overline{\tau}_{25} = \overline{\alpha}_{25} - \overline{\alpha}_{0}$).

- $\overline{\alpha}_{(footwear,\ \theta)}$ is used to represent the sacrum angle when stood on a surface of θ° in *footwear*. e.g. $\overline{\alpha}_{(sh,\ 20)}$ is the mean sacrum angle for females stood in small heels on the 20° surface gradient.

- $\overline{\tau}_{(footwear,\ \theta)}$ is used to define the difference between $\overline{\alpha}_{(footwear,\ \theta)}$ and $\overline{\alpha}_{(footwear,\ 0)}$. i.e. $\overline{\tau}_{(hh,\ 15)} = \overline{\alpha}_{(hh,\ 15)} - \overline{\alpha}_{(hh,\ 0)}$.

8.2 Male and Female Sacrum Angle Results

The sacrum angle of the male subjects standing on downhill surfaces does not show any significant changes from standing on the horizontal. However, the sacrum angle increases significantly when the males stood on surface gradients ≥ 20°. From the surface gradient of 20° the sacrum angle increases as the surface gradient increases (see Table 8-1).

Like the male subjects, the female subjects sacral angle starts increasing significantly on surface gradients ≥ 20°, however, the 30° uphill measurement is less significant at p=0.087 (see Table 8-2). This is likely due to there being far fewer people able to stand on a surface inclined at

30° and those people more affected by the slope are the ones not able to stand on the 30° inclines, thus skewing the results. The female subjects also showed significant reductions in sacral angle on surfaces of -10° and -20° ($p < 0.05$).

Table 8-1 - Males Sacrum Angle

Surface Angle (θ)	Males Barefoot		
	$\overline{\alpha}_\theta$	$\overline{\tau}_\theta$	
	mean (S.D.)	mean (S.D.)	*p*-value
-30	11.3° (7.6°)	0.1° (9.3°)	0.933
-25	11.8° (7.8°)	0.6° (8.4°)	0.641
-20	10.7° (7.5°)	-0.5° (6.9°)	0.682
-15	9.3° (7.4°)	-1.8° (7.9°)	0.158
-10	11.6° (8.1°)	0.5° (6.4°)	0.624
-5	11.8° (8.8°)	0.6° (10.1°)	0.697
0	11.1° (9.4°)	N/A	
5	9.2° (8.2°)	-1.9° (7.8°)	0.124
10	9.7° (8.2°)	-1.5° (9.9°)	0.352
15	12.9° (8.1°)	1.8° (8.7°)	0.199
20	16.1° (10.5°)	5.0° (9.3°)	0.002
25	21.4° (10.7°)	10.3° (11.0°)	<0.001
30	27.2° (12.3°)	16.1° (11.9°)	<0.001

Table 8-2 - Females Sacrum Angle

Surface Angle (θ)	Females Barefoot		
	$\overline{\alpha}_\theta$	$\overline{\tau}_\theta$	
	mean (S.D.)	mean (S.D.)	*p*-value
-30	14.4° (9.6°)	-4.9° (15.5°)	0.068
-25	18.3° (12.5°)	-0.1° (17.5°)	0.963
-20	13.4° (10.2°)	-5.1° (15.0°)	0.045
-15	16.4° (15.6°)	-2.1° (18.1°)	0.489
-10	12.9° (10.0°)	-5.6° (16.8°)	0.048
-5	17.9° (8.9°)	-0.6° (11.2°)	0.753
0	18.5° (14.0°)	N/A	
5	18.6° (13.1°)	0.1° (20.7°)	0.969
10	20.5° (12.9°)	2.1° (17.2°)	0.466
15	20.3° (16.7°)	1.8° (18.0°)	0.538
20	28.8° (15.0°)	10.3° (20.5°)	0.004
25	30.3° (15.7°)	12.1° (22.3°)	0.003
30†	26.2° (6.7°)	5.2° (14.9°)	0.087

† n = 13 for θ = 30°

The average sacrum angle of males and females at the various surface gradients is shown in Figure 8-2. This graph clearly shows the increasing sacrum angle of both genders as the gradient increases. The results of the independent *t*-tests between the male and females subjects show that the female subjects have a greater sacrum angle than the male subjects for all measured surface angles. The difference between the male and female subjects is significant for surface gradients of 0°, -5°, -15° and -25° as well as all uphill surfaces except 30° (see Table 8-3). The largest difference between male and females sacral angle occurs on the 20° surface, which is the gradient at which the difference between male and female thoracolumbar offset was greatest. Figure 8-2 also highlights the changes in the female sacrum angle between adjacent downhill surface gradients. It seems as though this effect is caused by the subjects maintaining balance in a different manner, i.e. by changing other elements of their posture such as the legs, ankles and trunk. Given that the subjects stepped off the platform and rested between measurements at different surface gradients this is possible.

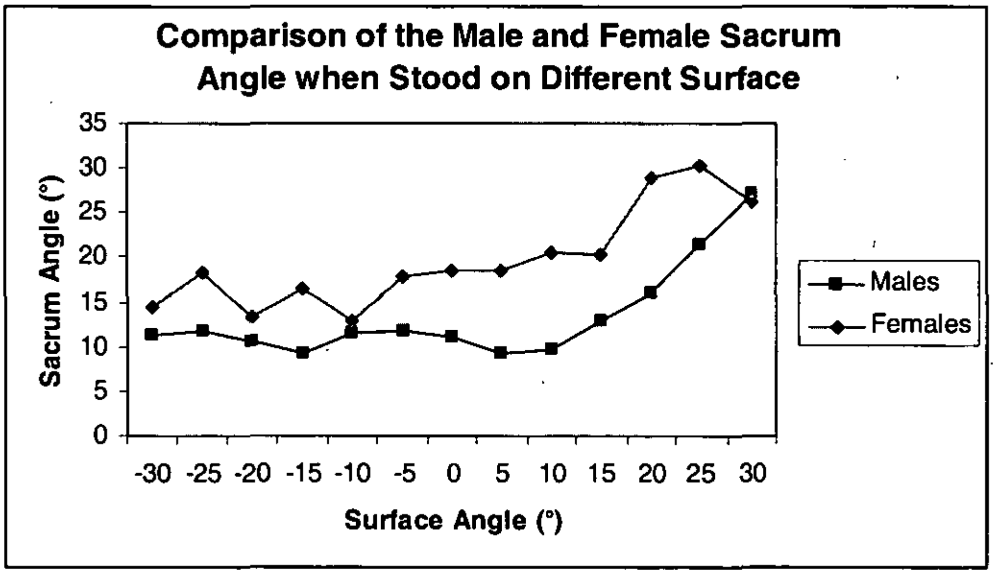

Figure 8-2 - Graph Showing the Effects of Surface Gradient on the Male and Female Sacrum Angle

Table 8-3 - Differences between Male and Female Sacrum Angle for Different Surface Angles

Surface Angle (θ)	Female $\overline{\alpha}_{\theta}$ - Male $\overline{\alpha}_{\theta}$	
	mean	*p*-value
-30	3.1°	0.120
-25	6.6°	0.006
-20	2.7°	0.179
-15	7.1°	0.014
-10	1.3°	0.532
-5	6.1°	0.003
0	7.3°	0.008
5	9.4°	<0.001
10	10.9°	<0.001
15	7.4°	0.015
20	12.7°	<0.001
25	8.8°	0.006
30	1.0°	0.681

8.3 Female Sacrum Angle Comparison of Different Footwear

This section describes the changes to the female subjects' sacrum angle caused by standing on different surface gradients in different footwear. Firstly, the effect of surface gradient on mean sacrum angle in females wearing small heeled and high heeled shoes is investigated. Secondly, for each surface gradient, one-way ANOVA for repeated measures was used to compare the effect of each pair of shoes on the sacrum angle.

The female subjects' sacrum angle when wearing the small heeled shoes was less when stood on any of the non-horizontal surfaces than it was when stood on the horizontal (see Table 8-4). This reduction in sacral angle was significant for $\overline{\tau}_{(sh,\theta)}$ when θ = 5°, 10°, 15° and all the downhill gradients except -10° ($p < 0.05$). Surface inclination had less of an effect on the female subjects when they were wearing high heeled shoes (see Table 8-5). Although the sacrum angle was reduced by standing on a downhill surface it was never significantly different. The only significant difference was the increase in sacrum angle for $\overline{\tau}_{(hh, 25)}$ ($p < 0.05$). For the uphill surface gradients as the surface gradient increases the sacrum angle also increases.

Table 8-4 - Females Small Heels Sacrum Angle

Surface Angle (θ)	Females Small Heels		
	$\overline{\alpha}_{(sh, \theta)}$	$\overline{\tau}_{(sh, \theta)}$	
	mean (S.D.)	mean (S.D.)	*p*-value
-30*	12.5° (9.4°)	-8.5° (14.2°)	0.010
-25+	15.3° (9.2°)	-5.9° (12.2°)	0.005
-20	14.7° (10.3°)	-6.5° (14.6°)	0.009
-15	16.3° (9.4°)	-4.9° (11.9°)	0.015
-10	18.4° (10.4°)	-2.8° (14.0°)	0.226
-5	15.2° (10.4°)	-6.0° (14.3°)	0.013
0	21.2° (11.4°)	N/A	
5	15.7° (9.9°)	-5.5° (13.4°)	0.015
10	15.0° (9.5°)	-6.2° (13.7°)	0.008
15	16.1° (11.7°)	-5.2° (15.6°)	0.049
20	18.5° (13.6°)	-2.7° (16.3°)	0.308
25+	16.6° (12.9°)	-4.6° (18.1°)	0.125
30*	20.7° (13.1°)	-0.3° (17.1°)	0.931

* n = 11 for θ = -30° and 30°

The lowering of the sacrum angle on non-horizontal surfaces when wearing either of the pairs of heeled shoes complements the lowering of the thoracolumbar offset when stood on non-horizontal surfaces in heeled shoes. It is possible that this decrease is due to an uncertainty about the posture to adopt on these surfaces as this might not have been a scenario that the subjects had experienced before, unlike standing on horizontal ground in heeled shoes.

Table 8-5 - Females High Heels Sacrum Angle

Surface Angle (θ)	Females High Heels		
	$\overline{\alpha}_{(hh,\theta)}$	$\overline{\tau}_{(hh,\theta)}$	
	mean (S.D.)	mean (S.D.)	*p*-value
-30[*]	12.4° (11.1°)	-4.6° (17.9°)	0.489
-25[+]	12.3° (9.5°)	-3.9° (14.5°)	0.170
-20[^]	13.1° (13.3°)	-2.5° (14.7°)	0.349
-15	12.9° (8.7°)	-2.6° (11.0°)	0.183
-10	14.6° (10.2°)	-1.1° (13.2°)	0.625
-5	14.0° (10.0°)	-1.7° (14.6°)	0.499
0	15.7° (9.0°)	N/A	
5	13.9° (10.7°)	-1.8° (10.6°)	0.308
10	14.2° (12.2°)	-1.5° (14.3°)	0.532
15	17.8° (14.9°)	2.1° (16.4°)	0.444
20[^]	17.6° (6.9°)	2.2° (10.5°)	0.236
25[+]	20.8° (8.8°)	4.7° (11.0°)	0.032
30[†]	26.3° (17.3°)	10.5° (15.9°)	0.066

[*] n = 4 for θ = -30°
[+] n = 15 for θ = -25° and 25°
[^] n = 17 for θ = -20° and 20°
[†] n = 5 for θ = 30°

A comparison of the female sacral angle for each surface and for the different types of footwear is shown in Figure 8-3. The effect of footwear on the female sacrum angle when the subject is standing on the horizontal is not significant. The female sacrum angle is also not generally affected by any of the downhill surfaces either as shown in Table 8-6. However, there is a significant reduction in female sacrum angle between wearing heeled shoes and standing barefoot on inclined surfaces of 10° and ≥ 20°. The effect of heel height on the female sacrum angle is not significant for any of the measured surfaces.

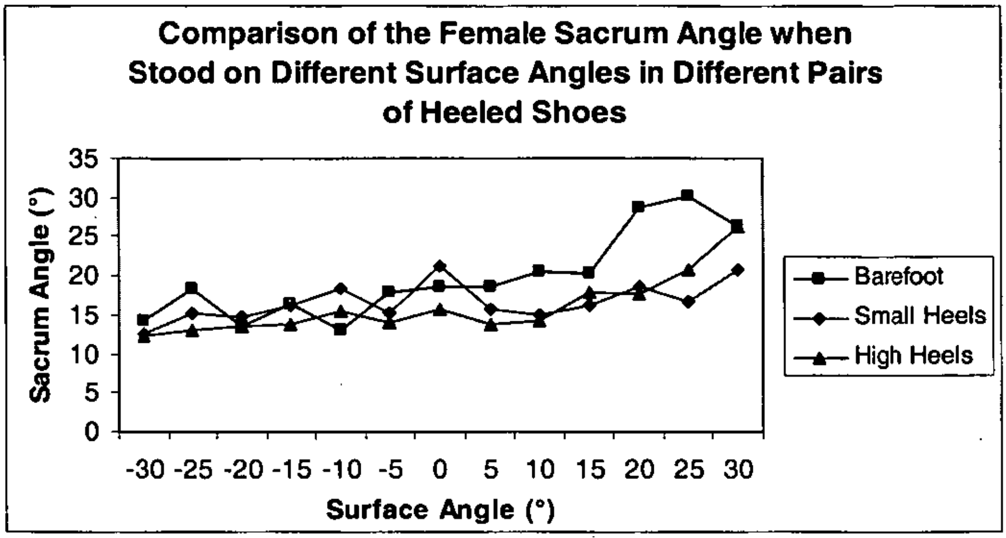

Figure 8-3 – Graph Showing the Effects of Heeled Footwear and Surface Inclination of the Female Sacrum Angle

Table 8-6 - Pairwise Comparison of Female Sacrum Angle When Wearing Different Footwear on Different Surface Gradients

Surface Angle (θ)	Pairwise Comparison					
	$\overline{\alpha}_{\theta} - \overline{\alpha}_{(sh,\theta)}$		$\overline{\alpha}_{\theta} - \overline{\alpha}_{(hh,\theta)}$		$\overline{\alpha}_{(sh,\theta)} - \overline{\alpha}_{(hh,\theta)}$	
	Mean	Sig.	Mean	Sig.	Mean	Sig.
-30*	-1.8	NS	3.9	NS	5.6	NS
-25+	2.5	NS	5.9	0.025	3.4	NS
-20^	-2.2	NS	-0.4	NS	1.9	NS
-15	0.1	NS	2.3	NS	2.3	NS
-10	-5.5	0.021	-2.6	NS	2.9	NS
-5	2.6	NS	3	NS	0.4	NS
0	-2.2	NS	2.3	NS	4.5	NS
5	2.9	NS	3.4	NS	0.4	NS
10	5.6	0.023	5	0.043	-0.5	NS
15	4.2	NS	1.9	NS	-2.3	NS
20^	10.6	0.001	11	<0.001	0.4	NS
25+	16	<0.001	11.3	0.001	-4.8	NS
30†	17.8	0.002	19.3	0.034	1.5	NS

* n = 4 for θ = -30°
+ n = 15 for θ = -25° and 25°
^ n = 17 for θ = -20° and 20°
† n = 2 for θ = 30°.
NS - Not Significant
Sig. – Significance

8.4 Conclusions

For both male and female subjects, the sacrum angle is significantly different when standing on surfaces of 20° and greater, than when standing on the horizontal. For each of the measured surfaces, the male subjects had a lower sacral angle than the female subjects, this was significant for $\theta = -25$, -15 and -5 to 25° ($p < 0.05$). On the downhill surfaces, males showed no significant differences between standing on downhill surfaces and standing on a horizontal surface. For the female subjects, there were significant decreases at -10° and -20° ($p < 0.05$). There is not a linear relationship between sacrum angle and surface gradient.

As discussed in Section 6.4 it is thought that the range of motion of the ankle has an effect on the thoracolumbar offset of a subject. As the thoracolumbar offset is affected by changes in the pelvis, this argument could be extended to state that the sacral angle is also affected by the limited range of motion of the ankle joint in dorsiflexion.

The effect of wearing heeled shoes on a horizontal surface was not significant for either of the pairs of shoes. However, when standing on inclined surfaces of 10° or 20° and greater the effect of heels was to significantly decrease the sacral angle. The effect of surface gradient on the sacral angle of females wearing small heeled shoes was to reduce the sacral angle, this is significant for $\bar{\tau}_{(sh,\theta)}$ where $-30° \leq \theta \leq 15°$ excluding -10° ($p < 0.05$). When the female subjects wore the high heeled shoes, the effect of surface gradient on the sacrum angle was not significant except for $\bar{\tau}_{(hh,25)}$ where there was a significant increase in sacral angle.

Chapter 9 - Conclusions

The aim of this thesis was to observe the effects of different surface gradients and footwear on standing posture. The elements of posture that are measured are the thoracolumbar offset, the sacrum and the thoracic and lumbar curves of the spine. Changes in any of these parameters will cause a deviation from the ideal, efficient posture, resulting in increased muscle activity. Research was then conducted into appropriate methods for determining trunk lean and curvature measurement. The SpinalMouse® was used to measure the skin profile of 39 subjects, 20 males and 19 females. The resulting contours are input into software specifically developed for this research task. This software calculates the thoracolumbar offset angle and the thoracic and lumbar curvatures. Each of these spinal parameters is observed separately; this chapter will combine those results and examine the combined effects on all four parameters.

9.1 The Effects of Surface Gradient and Footwear on the Spine

For the male subjects, the sacrum angle and the thoracolumbar offset angle both increase, at 20° and steeper they are significantly greater than when standing on the horizontal. At steep surface angles both the thoracic and lumbar curvatures decrease, becoming flatter. There are no significant differences in the measured spinal parameters between standing on any of the downhill surfaces and standing on the horizontal.

Like the male subjects, the female subjects experienced increased sacrum and thoracolumbar offset angles between standing on inclined surfaces and standing on a horizontal surface. Also like the male subjects, the female subjects adopted flatter thoracic and lumbar curves in order to maintain balance on steep inclines. On downhill surfaces the female subjects did change their thoracic curvatures, their thoracolumbar offset and their sacrum angles. The thoracic curvature became more curved and both the thoracolumbar offset and the sacrum angle decreased.

For most surfaces, the female subjects had a higher sacrum angle, higher thoracolumbar offset angle and more curvature in both thoracic and lumbar spines.

When the female subjects were wearing the small heeled pair of shoes, standing on inclined surfaces caused a reduction in thoracolumbar offset and at surfaces ≥ 15° a reduced sacrum angle. No changes were seen in the thoracic and lumbar curvatures between standing on inclined surfaces and standing on the horizontal. When standing on downhill surfaces, thoracolumbar offset and sacrum angle decrease, thoracic curvature increases at surfaces of -25° up to -5° but lumbar curvature demonstrates no changes between standing on downhill surfaces and standing on the horizontal.

When the female subjects wearing the high heeled shoes stood on inclined surfaces, their thoracolumbar offset angle and their sacrum angles decreased on the shallow gradients and increased on the steeper surface gradients. The effects on thoracic and lumbar curvature was to make them more curved especially on surfaces of 15° to 25°. When the female subjects in high heeled shoes stood on downhill surfaces their thoracolumbar offset angle and sacrum angles were decreased, but not significantly. Their thoracic curvatures became more curved especially on the -20° and -15° surfaces and lumbar curvatures became more curved especially on the -5° surface.

When standing on inclined surfaces of 10° and steeper, wearing heeled footwear caused a decrease in the thoracolumbar offset and sacrum angle. The heeled shoes also caused increases in both the thoracic and lumbar curvatures, although the increases in lumbar curvature were not significant. The height of the heel only affected the thoracolumbar offset for the 25° surface.

Wearing small heeled shoes on a horizontal surface has no effect on the thoracolumbar offset, the sacrum angle, the thoracic or lumbar curvatures. Wearing the high heeled shoes on a horizontal surface does not affect thoracolumbar offset, the sacrum angle or the thoracic curvature; however, there is a significant decrease in the lumbar curvature. Clearly there is a difference caused by the height of the heels.

The effect of wearing heeled footwear on downhill surfaces is negligible. There is a flattening of the lumbar curvature but this is not significant. Thoracolumbar offset, sacrum angle and thoracic curvature are unaffected by standing on downhill surfaces down to -30°. No effect was seen due to heel height.

In cases where the whole spine changes, there appear to be two types of behaviour. The first one involves the sacrum rotating backwards, the thoracolumbar offset decreasing and the thoracic and lumbar curves becoming more accentuated. The other involves the sacrum rotating forward, the thoracolumbar offset increasing and the thoracic and lumbar curves becoming flatter.

A final observation is that wearing heeled shoes on the shallower surfaces actually reduced the effect that the surface has on posture, i.e. the person was closer to their natural posture when wearing heeled shoes on an inclined surface than when they were not wearing the heeled footwear on the same inclined surface.

There were only very subtle differences between the two measurement techniques and the two measurement ranges. This, to some degree, was to be expected as the T12/L1 intervertebral joint is not that mobile and the measurement techniques are very similar.

9.2 Research Boundaries

Subjects were measured wearing thin clothing and female subjects were not asked to remove or unclasp their bras. Given that the SpinalMouse®

should be run directly over the skin the measurements may not represent the subjects' exact spinal contours. It should be noted however that none of the clothing worn by the subjects was baggy and there were no problems such as snagging or ruffles in the clothing that the SpinalMouse® went over.

Loughborough University regulations require that the subjects were asked whether they were healthy, free from any pain and able to stand on the different surface gradients. The gastrocnemius-soleus complex muscle group and the talocrural joint both have an effect on the posture adopted by a person, therefore it would be useful to have specifically asked whether they had any known leg or ankle problems. A method which does not rely on human perception such as EMG could give an objective view, but was outside the scope of this research project.

This research used the SpinalMouse® product's determination of the position of the vertebral bodies. The method that this device uses to compute the original vertebral positions is commercially protected. However, previous studies have determined that the SpinalMouse® is a reliable and viable measurement method.

9.3 Future Work/Development

This study focused on static, standing posture. Future studies could focus on walking uphill or downhill in heeled footwear which has not been investigated before and would build on the research conducted in this project.

Another alternative study could observe and detect whether there is a difference between getting off the inclined surface whilst it was being raised and increasing the surface gradient with the subject remaining on the surface, like a treadmill can be raised while walking on it. The data from any measurement device which measures the intervertebral angles can be input into the software developed in this research.

Using the measurement data taken in this study, future research projects could determine where the majority of the thoracolumbar lean is coming from on a regional or intervertebral basis. i.e. thoracic lean and lumbar lean, or the difference between the intervertebral angle T12/L1 at different surface angles.

Alternative methods could be used to determine the transition vertebra. Instead of using the T12 and L1 vertebra for every subject, the transitional vertebra could be calculated on an individual subject basis. This was not done for this study as the effect of surface gradient and footwear could change the transition vertebra resulting in problems comparing the curvatures on different surfaces.

Both the male and female curvatures used the same vertebral measurement breakdown from Acar and Grilli [82]. This could be parameterized to output the spinal curves and results using any vertebral breakdown measurements given that the spinal curves are stored as intervertebral angles, a length and a sacrum angle.

9.4 Contribution to Knowledge

This research has studied four spinal parameters simultaneously and focused on each gender separately. This research has used a wide range of surface gradients up to ±30° compared to other studies in the literature. Few studies have researched the heels of shoes affecting the thoracic curvature and few have researched males on inclined/declined surfaces due to declined surfaces generally being used to represent heeled footwear. No previous studies have looked at the effects of heeled footwear on different surface gradients.

The software that has been developed can be used for future studies which use the SpinalMouse®, or any other measurement technique which outputs intervertebral angles, and require the calculation of thoracic and lumbar angles of curvature or the thoracolumbar offset angle. Additional

Java™ classes can be written and integrated into the software to produce additional spinal calculations.

This research has shown that on horizontal ground high heeled shoes caused a reduction in lumbar curvature, it is therefore recommended that people should avoid wearing high heeled shoes, especially for long periods. For inclined surfaces, given that thoracolumbar offset and the thoracic and lumbar curves are all affected suggests that standing and other activities performed on inclined surfaces should be avoided if possible. As the inclined surface gradient increases, a person will lean further into the slope and straighten the curves of their spine. The combination of lean and change in curvature puts a person at increased risk of back pain. This occurs when the slope becomes steeper than or equal to 20°. It is believed that before this 'critical' surface angle, the ankle joint is able to absorb the effect of the slope rather than the spine having to reconfigure itself in order to maintain balance.

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Glossary

achondroplasia – A genetic (inherited) condition that results in abnormally short stature.

anterior – Front.

anteroposterior (A-P) – front to back.

absolute rotation angle (ARA) – A method of measuring spinal curvature. It is the angle formed from the lines which pass through the posterior vertebral body boundaries of the start and end vertebrae of the curve.

articular – Referring to the area where adjacent bones contact each other to form a joint.

axial – The plane that divides the human body into top and bottom.

bicoxofemoral axis – The axis between the femoral heads (where the femurs joins the pelvic girdle).

binary image – An image made up of only black and white pixels.

cauldal – Toward the coccyx.

congenital – The condition is present at birth.

cranial – Toward the head.

comma separated variable (CSV) – A common file standard for transferring data between different programs or different installations of the same program where variables are separated by commas.

discitis – Infection of the intervertebral disc.

electromyography (EMG) – A record of the electrical activity of muscle.

etiology – Cause of a disease.

extension – Straightening a joint. Extension of the spine occurs when a person bends backwards.

facet – A small, smooth articular surface.

flexion – Bending a joint. Sagittal flexion of the spine occurs when a person bends forwards as though touching their toes. Lateral flexion occurs when a person bends to the side.

foramen – An opening through a bone.

gastrocsoleus complex – The muscle system more commonly known as the calf muscle.

human computer interaction (HCI) – The study of how humans interact with computers.

idiopathic – The cause is unknown.

ilia/ilium – Relating to the expansive cranial portion of the hip bone

inclinometer – An electronic device which measures the angle to the horizontal (also known as a potentiometer).

inferior – Below, bottom.

lateral – The plane that divides the human body into the front and rear sections, a lateral view is a view parallel to the lateral plane.

moiré – The interference pattern created when two sets of parallel lines are overlaid at different angles.

occiput – The back part of the head or skull.

osteoporosis – A disease which decreases bone density which can cause the vertebrae to loose strength.

paravertebrally – Running parallel and as close to the line of spinous processes as possible but not over them.

posterior – Rear, behind.

process – A relatively large projection or prominent bump.

radiculopathy – A disease of the spinal nerve roots.

rasterstereography – A 3D measuring technique in which parallel white laser lines are projected onto a surface and the patterns that the light makes as it hits the surface are captured by a camera and processed.

sagittal – The plane that divides the human body into left and right sides.

spinal cord injury (SCI) – Spinal cord injuries affect motor and sensory function. The American Spinal Injury Association (ASIA) classifies five levels of SCI, from A to E. Impairment level A is complete with no motor or sensory function below the injury site, level E is normal where although an injury exists, motor and sensory function is within normal ranges.

subluxation – Incomplete or partial dislocation of a joint.

superior – Above, top.

supine – Lying down on one's back.

Tesla – The SI unit for measuring magnetic field intensity.

tragus – The prominence in front of the opening of the external ear.

Appendices

Appendix 1

The following tables provide the thoracolumbar offset angles, Shoun and Leroux angles and the sacrum angle for each subject on each surface gradient. Tables A-1 through A-13 show these results for barefoot males. Tables B-1 through B-13 show these results for barefoot females. Tables C-1 through C-13 show these results for females wearing the small heeled pair of shoes and Tables D-1 through D-13 show these results for females wearing the high heeled pair of shoes. As not all subjects were able to stand on all surfaces there are some data missing.

Table A-1 – Males Standing Barefoot on a Surface Gradient of 0°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	0.8	35.2	35.2	34.7	35.2	17.6	21.9	15.7	22.4	17
1	2	2.2	34.8	36.1	35.0	35.5	13.9	17.3	12.3	17.5	11
2	1	2.6	44.9	44.9	45.3	46.0	15.4	19.2	18.3	18.6	13
2	2	1.3	46.3	46.3	46.7	47.4	18.3	18.4	20.0	20.3	13
3	1	1.6	41.8	43.4	44.5	45.2	9.6	12.0	7.8	11.0	0
3	2	1.5	46.6	48.4	47.5	48.2	8.6	10.7	6.7	9.6	0
4	1	1.5	29.2	29.2	32.8	32.9	14.4	18.0	12.6	18.0	5
4	2	-0.8	25.6	29.6	28.7	29.1	11.7	14.6	10.5	14.9	1
5	1	5.4	39.0	40.6	40.0	40.7	11.8	14.7	8.9	12.6	9
5	2	4.9	37.8	39.3	38.3	38.8	12.3	15.3	8.9	12.6	12
6	1	3.1	41.5	42.9	45.1	45.2	25.4	25.5	26.6	27.1	16
6	2	3.7	48.2	49.8	51.8	52.0	26.4	26.5	28.3	28.8	15
7	1	0.3	47.3	48.9	53.1	53.2	4.9	6.1	4.5	4.8	-7
7	2	3.3	39.8	41.1	47.9	50.5	14.9	18.6	12.0	17.0	2
8	1	0.0	52.8	61.8	51.8	52.7	30.2	30.3	34.6	35.2	20
8	2	0.0	50.8	53.2	50.7	51.6	31.1	31.3	33.6	34.2	19
9	1	4.3	31.3	32.3	37.7	39.7	3.7	4.7	2.5	3.5	-1
9	2	5.3	44.6	44.6	50.3	50.4	3.3	4.1	3.0	4.9	-3
10	1	4.9	48.0	49.7	52.2	52.3	48.9	61.1	46.1	66.1	19
10	2	2.8	43.3	44.8	49.7	49.9	48.6	48.8	50.8	51.7	30
11	1	4.5	40.3	41.7	44.1	44.3	16.3	16.4	17.7	18.0	14
11	2	1.6	41.8	43.3	46.0	46.1	15.2	15.3	16.0	16.3	6
12	1	5.7	47.0	47.0	48.9	49.0	26.8	37.2	40.4	43.0	27
12	2	5.6	38.4	39.8	44.6	44.7	39.7	39.8	40.7	41.4	19
13	1	-2.2	34.9	34.9	38.8	38.9	10.1	10.2	12.6	12.8	2
13	2	0.4	39.5	39.5	40.2	40.8	20.4	20.5	21.0	21.4	16
14	1	5.4	64.3	64.4	65.5	66.5	22.2	22.3	24.5	24.9	12
14	2	7.0	68.1	68.1	68.5	69.6	22.3	22.4	24.2	24.6	15
15	1	-2.8	47.2	47.2	47.0	47.6	21.2	21.3	25.1	25.5	9
15	2	-1.0	45.4	45.4	43.1	43.8	26.2	26.3	30.0	30.5	25
16	1	0.1	52.3	54.6	51.8	56.6	26.3	26.4	25.0	25.4	9
16	2	1.7	52.8	55.0	53.4	54.2	29.2	29.3	26.9	27.4	7
17	1	3.3	55.0	55.0	54.3	55.1	49.5	49.7	52.6	53.6	20
17	2	2.3	52.8	52.8	52.3	53.1	46.1	46.3	50.0	50.9	36
18	1	3.8	37.1	43.2	46.2	48.8	12.2	15.2	8.8	12.6	-1
18	2	5.8	44.3	45.8	51.9	54.7	16.0	19.9	13.6	19.4	4
19	1	6.2	63.6	65.8	70.9	71.1	14.2	14.3	14.7	14.9	7
19	2	7.4	62.1	64.3	69.1	69.4	16.0	19.9	14.3	20.4	11
20	1	-0.4	37.6	39.0	39.5	40.1	25.3	31.5	21.2	30.2	9
20	2	-4.9	24.9	24.9	27.5	27.6	16.5	20.5	16.7	17.0	7

Table A-2 – Males Standing Barefoot on a Surface Gradient of 5°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	1.5	34.2	35.6	33.4	33.9	12.8	15.9	11.5	16.4	16
1	2	3.1	35.2	36.6	34.6	35.2	19.7	24.5	17.1	24.4	14
2	1	-2.3	39.2	45.7	38.2	47.6	17.3	17.3	20.5	20.9	8
2	2	1.9	40.7	47.4	38.1	38.7	17.0	21.1	19.4	20.6	17
3	1	1.3	39.2	39.2	41.7	42.2	11.2	11.2	10.4	10.6	0
3	2	1.1	39.4	39.4	42.1	42.2	12.8	15.9	12.1	12.3	2
4	1	-0.8	24.5	25.4	27.9	28.0	7.3	8.0	9.1	9.1	8
4	2	-1.5	29.2	29.2	31.6	32.1	7.3	8.0	9.1	9.1	6
5	1	4.5	43.0	43.1	45.4	45.5	6.7	9.3	8.8	9.3	-5
5	2	6.2	44.3	51.5	45.5	46.2	6.6	9.2	8.6	9.2	-2
6	1	2.4	45.3	47.1	45.8	49.8	20.3	20.4	21.3	21.7	10
6	2	2.2	45.9	47.8	46.2	50.2	19.3	19.4	20.7	21.0	11
7	1	2.4	34.9	34.9	40.9	41.0	15.5	19.3	12.0	17.1	4
7	2	2.4	35.8	37.0	43.9	46.2	19.7	24.5	15.8	22.5	8
8	1	-0.2	62.4	65.0	61.2	62.3	25.5	31.8	24.8	25.2	8
8	2	1.3	57.6	60.0	56.0	61.2	34.2	34.3	36.6	37.2	20
9	1	1.3	35.4	36.6	42.9	45.3	15.0	15.1	12.9	13.1	-6
9	2	4.3	44.7	46.3	53.7	56.7	11.1	11.2	10.7	10.9	1
10	1	0.6	45.1	46.7	52.5	55.4	33.6	33.7	36.0	36.6	10
10	2	0.3	48.8	50.4	53.9	54.1	39.4	39.5	42.3	43.1	34
11	1	1.4	31.8	32.9	34.7	34.8	14.2	14.3	15.3	15.6	11
11	2	2.3	35.9	37.1	39.3	39.4	7.1	8.1	8.1	8.1	8
12	1	4.2	37.9	37.9	42.8	42.9	34.4	34.5	36.5	37.1	12
12	2	3.9	38.5	38.5	43.2	43.3	38.6	38.7	40.3	41.0	15
13	1	-0.7	31.3	31.3	33.5	34.0	10.7	13.2	10.4	10.6	2
13	2	-2.1	36.5	36.5	38.9	39.0	8.0	10.0	8.0	8.2	-1
14	1	5.5	61.5	61.5	62.4	63.4	18.2	18.3	20.8	21.2	13
14	2	6.1	64.4	64.4	65.4	66.4	20.2	20.3	22.5	22.9	14
15	1	-3.6	44.5	44.5	43.4	44.0	11.9	13.0	15.1	15.1	11
15	2	-6.5	37.3	37.3	36.8	37.3	18.1	18.1	21.7	22.0	11
16	1	-1.7	45.3	45.3	47.3	47.4	29.3	29.5	29.2	29.8	10
16	2	-2.1	46.8	48.7	46.5	47.2	45.2	45.4	42.0	42.8	14
17	1	2.6	46.8	48.6	45.4	49.4	43.3	43.5	46.9	47.7	30
17	2	4.8	61.5	64.0	60.0	60.9	50.4	50.6	53.2	54.2	14
18	1	6.3	50.0	51.8	59.2	62.5	16.5	20.6	14.7	20.9	1
18	2	7.2	45.2	46.8	54.3	57.3	9.6	12.0	7.4	10.6	-2
19	1	5.5	61.1	63.2	68.1	68.3	16.3	16.3	16.4	16.7	9
19	2	6.0	57.4	59.4	64.0	64.2	14.9	18.5	13.8	14.0	7
20	1	-2.2	23.7	24.5	25.3	26.6	14.2	14.3	16.3	16.5	9
20	2	-2.0	24.9	25.8	25.5	25.6	18.2	18.3	19.9	20.3	16

Table A-3 – Males Standing Barefoot on a Surface Gradient of 10°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	2.6	35.2	36.6	33.5	36.4	19.7	24.5	17.5	24.9	15
1	2	3.1	34.1	39.6	31.7	39.4	19.7	24.5	17.8	25.4	19
2	1	6.0	45.6	45.6	44.5	45.2	22.1	22.2	25.7	26.1	16
2	2	5.8	44.5	51.9	41.7	45.5	21.2	21.3	25.4	25.8	18
3	1	0.2	41.3	41.3	43.1	43.7	12.8	15.9	12.1	12.3	3
3	2	2.7	42.2	42.2	44.3	44.9	10.1	12.6	8.4	12.0	0
4	1	-1.2	26.7	26.7	28.6	29.0	16.0	19.9	15.4	15.7	8
4	2	-1.9	31.4	32.7	32.6	32.7	17.0	21.2	18.0	18.3	10
5	1	5.9	43.4	43.4	46.3	46.4	5.2	7.2	4.9	5.3	-1
5	2	4.0	46.0	47.9	46.1	46.8	11.2	14.0	8.8	12.5	6
6	1	2.5	43.2	44.9	44.1	44.7	24.4	24.5	25.3	25.8	15
6	2	4.8	41.4	41.4	45.4	45.5	19.3	19.4	20.6	21.0	13
7	1	2.4	34.1	34.1	39.4	41.5	18.7	23.2	14.8	21.0	7
7	2	1.2	30.6	31.6	37.2	39.2	13.9	17.3	9.6	13.6	5
8	1	3.1	52.3	54.5	50.9	55.5	29.1	29.3	32.3	32.8	21
8	2	2.0	46.4	48.4	44.5	48.5	30.4	30.5	35.1	35.7	23
9	1	2.4	38.5	39.8	46.1	46.3	5.9	7.3	3.9	5.6	-9
9	2	5.0	38.8	40.1	49.2	52.0	10.2	12.7	8.1	11.5	-3
10	1	1.5	31.8	32.9	40.0	42.2	18.2	18.3	14.5	14.7	-17
10	2	1.3	35.8	37.0	42.5	42.6	22.2	22.3	20.0	20.4	7
11	1	0.7	33.8	35.0	37.5	39.5	9.6	12.0	8.4	12.0	4
11	2	3.1	39.9	41.2	43.3	43.4	17.1	21.2	16.8	17.1	13
12	1	3.2	36.0	36.0	40.1	40.3	37.5	37.7	39.5	40.3	13
12	2	4.1	36.6	36.6	39.6	39.7	42.4	42.6	44.4	45.1	14
13	1	-0.2	34.2	35.4	36.8	36.9	11.2	11.3	12.3	12.5	7
13	2	-0.3	33.1	33.1	35.4	35.5	7.3	8.0	7.1	7.1	7
14	1	6.3	64.0	64.1	65.5	66.5	20.3	20.4	23.5	23.9	12
14	2	6.4	61.6	61.6	63.1	64.0	18.2	18.3	21.2	21.6	9
15	1	-2.9	44.8	44.8	42.9	43.5	17.1	17.2	19.8	20.1	9
15	2	-2.3	41.9	41.9	39.9	40.4	15.2	15.3	18.8	19.2	10
16	1	-3.6	44.9	46.8	44.5	45.2	28.0	28.1	24.8	25.2	3
16	2	-1.0	46.6	48.5	49.1	49.2	33.5	41.7	34.0	34.7	17
17	1	0.9	55.1	55.1	55.2	56.0	33.4	33.6	36.8	37.4	20
17	2	3.5	57.5	57.5	57.2	58.0	42.6	42.8	47.4	48.3	22
18	1	4.7	49.8	51.5	56.5	56.7	27.4	27.5	25.1	25.6	14
18	2	4.5	48.7	48.7	54.2	54.4	24.5	30.5	21.3	30.4	14
19	1	5.4	61.8	63.9	67.5	67.7	7.3	8.0	8.1	8.1	13
19	2	5.8	59.2	61.3	65.2	65.4	12.8	15.9	12.7	12.9	8
20	1	-1.7	24.6	24.6	25.5	25.6	14.1	14.2	15.9	16.2	9
20	2	-3.2	25.7	26.5	28.0	28.0	21.3	21.3	22.9	23.3	12

Table A-4 – Males Standing Barefoot on a Surface Gradient of 15°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	5.2	33.0	34.3	31.2	33.9	18.1	22.6	16.4	23.4	19
1	2	2.8	35.0	36.4	32.7	35.6	19.7	24.5	17.8	25.3	19
2	1	-1.2	50.1	50.1	50.8	51.6	25.4	25.5	28.6	29.1	13
2	2	2.8	41.2	42.8	40.4	41.0	20.2	20.3	25.1	25.5	14
3	1	0.0	39.6	39.6	43.0	43.1	12.8	15.9	10.8	15.4	2
3	2	2.0	42.6	42.6	44.6	45.2	6.4	8.0	5.7	5.8	-3
4	1	-1.7	29.9	31.0	31.8	31.9	15.2	15.3	16.6	16.9	7
4	2	-3.1	31.4	31.4	33.1	33.2	18.6	23.2	19.0	19.4	10
5	1	3.6	41.6	41.6	42.0	42.7	14.4	17.9	11.9	17.0	10
5	2	6.7	42.7	42.7	43.5	44.2	12.3	15.3	9.5	13.5	13
6	1	2.4	39.9	41.2	44.5	44.6	22.4	22.5	24.9	25.4	18
6	2	4.1	45.4	45.4	49.3	49.4	29.3	29.5	31.5	32.1	20
7	1	2.5	35.2	35.2	38.4	38.5	15.5	19.2	12.6	18.0	9
7	2	0.4	45.6	47.4	46.4	50.5	17.5	21.8	14.4	20.4	8
8	1	1.2	55.3	57.7	53.2	58.2	26.3	26.4	30.7	31.3	18
8	2	3.7	65.5	68.3	63.1	68.9	19.3	26.7	28.7	30.6	19
9	1	2.5	43.2	44.8	51.9	54.8	21.3	21.3	21.0	21.3	6
9	2	5.0	45.9	47.5	55.3	58.4	11.2	11.2	10.7	10.9	-3
10	1	2.7	44.2	45.7	53.3	56.2	38.6	38.7	39.0	39.7	17
10	2	4.0	48.6	50.3	55.5	55.7	31.5	31.7	33.0	33.6	18
11	1	-1.4	31.6	32.7	35.6	35.7	8.3	9.0	11.1	11.1	9
11	2	3.0	34.2	35.4	37.7	39.8	12.2	12.2	13.0	13.2	10
12	1	5.5	36.9	36.9	41.9	42.0	41.6	41.7	43.2	44.0	14
12	2	6.9	39.5	39.5	44.9	45.0	39.7	39.9	40.7	41.5	17
13	1	5.9	36.1	36.1	36.2	36.3	20.2	25.2	18.8	26.8	24
13	2	5.3	35.2	35.2	34.8	34.9	12.8	16.0	12.2	17.4	17
14	1	5.9	60.0	60.1	58.7	59.6	24.2	24.3	28.4	28.9	19
14	2	6.6	61.9	61.9	59.5	60.4	24.3	24.4	28.1	28.6	22
15	1	-4.1	40.4	42.0	39.6	40.2	11.2	11.3	15.9	17.0	2
15	2	-3.5	47.9	47.9	47.4	48.1	18.2	18.3	22.1	22.5	3
16	1	-1.7	46.5	48.4	46.6	47.3	41.2	41.4	40.3	41.0	14
16	2	-2.4	43.1	50.3	43.6	44.3	36.2	36.4	33.5	34.1	9
17	1	5.5	59.2	61.6	57.9	58.8	46.5	46.7	51.9	52.8	34
17	2	7.2	63.0	65.5	61.4	62.4	29.1	36.0	38.3	40.7	27
18	1	9.8	55.4	57.4	63.7	63.9	30.4	30.6	32.3	32.8	26
18	2	7.4	43.7	45.2	51.7	54.6	17.2	17.3	14.5	14.7	6
19	1	5.2	64.5	66.8	70.0	70.2	14.2	14.3	15.3	15.6	8
19	2	5.9	60.9	63.1	67.3	67.6	14.9	18.5	15.0	15.3	7
20	1	-1.2	22.6	23.3	23.0	23.1	11.1	11.2	12.9	13.1	6
20	2	-0.3	24.7	25.5	26.6	28.0	13.2	13.2	15.9	16.1	9

Table A-5 – Males Standing Barefoot on a Surface Gradient of 20°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	4.8	28.1	29.2	26.1	28.4	19.2	23.9	17.4	24.9	23
1	2	5.6	29.9	34.7	27.2	33.7	14.4	17.9	12.9	18.4	23
2	1	3.0	45.7	45.7	47.0	47.7	15.2	15.3	18.2	18.5	9
2	2	1.7	42.8	42.8	43.2	43.8	16.3	16.3	20.5	20.9	11
3	1	0.3	35.1	35.2	36.2	36.8	16.2	16.3	17.9	18.2	10
3	2	2.6	41.0	41.0	41.9	42.5	5.5	6.0	9.0	9.0	4
4	1	-0.6	26.3	26.3	27.8	28.2	18.3	18.4	19.3	19.7	12
4	2	-1.9	29.0	29.0	30.3	30.7	18.3	18.4	20.0	20.3	12
5	1	7.2	40.5	40.5	41.8	42.4	5.2	7.2	4.9	5.3	-1
5	2	5.3	41.3	48.1	40.9	44.6	2.7	3.4	4.8	5.2	-3
6	1	7.2	40.6	40.6	43.5	44.1	27.4	27.5	29.2	29.8	20
6	2	10.3	48.2	48.2	50.2	50.9	23.4	23.5	26.0	26.4	23
7	1	7.2	26.6	27.6	28.2	28.6	9.1	11.3	7.4	10.5	9
7	2	7.2	26.4	26.4	28.3	28.7	16.0	19.9	14.0	19.9	14
8	1	12.5	49.0	51.1	45.7	50.0	14.1	14.2	16.8	17.1	21
8	2	18.2	43.7	45.6	40.3	43.9	15.2	15.2	18.8	20.0	31
9	1	3.6	26.8	27.7	33.3	35.1	7.5	9.3	6.0	8.5	-2
9	2	6.7	34.3	35.5	41.0	43.3	4.8	6.0	3.2	4.6	-3
10	1	2.9	34.4	35.6	42.1	44.4	38.4	38.5	40.4	41.1	20
10	2	4.6	39.5	40.9	46.3	46.4	34.5	34.7	38.2	38.9	25
11	1	4.3	31.0	32.0	33.0	33.1	16.5	20.6	17.4	17.7	17
11	2	3.3	27.7	32.2	29.9	31.5	18.3	18.4	21.9	22.3	21
12	1	5.3	36.3	36.3	40.0	40.1	28.1	34.8	38.3	40.7	15
12	2	8.4	32.8	33.9	37.9	38.0	36.8	45.7	38.5	39.2	17
13	1	17.8	31.3	32.4	31.9	32.0	11.2	11.2	12.3	12.5	29
13	2	21.5	27.6	28.6	28.5	28.6	10.1	12.6	10.4	10.5	34
14	1	13.4	53.3	55.5	50.0	50.8	17.8	17.9	24.5	26.1	30
14	2	13.3	56.7	59.0	53.6	54.5	19.2	19.2	25.1	26.7	27
15	1	-4.2	36.2	36.2	34.5	35.0	15.2	15.3	20.4	21.7	9
15	2	-2.3	44.9	44.9	41.1	41.7	14.3	17.8	20.8	22.1	12
16	1	4.6	40.8	42.6	39.6	43.1	21.8	27.1	20.8	21.2	15
16	2	3.0	45.6	47.5	46.2	46.9	18.2	18.3	19.9	20.3	10
17	1	10.5	62.7	62.8	62.5	63.4	56.2	70.3	48.5	69.7	40
17	2	13.6	61.2	61.2	58.9	59.7	28.2	28.4	37.5	39.9	36
18	1	10.4	45.1	46.7	53.7	56.7	21.2	21.3	20.3	20.6	14
18	2	3.1	42.1	43.7	45.1	45.8	17.0	21.2	14.8	15.1	6
19	1	8.6	50.8	52.5	54.1	54.2	15.2	15.3	16.9	17.2	17
19	2	10.2	45.1	46.6	49.0	49.1	12.2	12.2	13.9	14.2	17
20	1	3.9	24.5	25.3	25.4	25.5	14.4	17.9	13.9	19.8	10
20	2	4.5	18.7	19.4	19.2	19.2	16.0	19.9	16.1	16.3	10

Table A-6 – Males Standing Barefoot on a Surface Gradient of 25°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	13.2	28.3	32.8	26.3	32.5	12.3	15.3	10.9	15.5	27
1	2	12.9	23.2	24.1	21.5	23.3	17.6	21.9	16.1	22.9	32
2	1	6.5	36.0	36.0	35.5	36.0	15.2	15.2	19.8	20.1	17
2	2	8.1	37.7	39.2	37.7	39.2	18.2	18.5	18.2	18.5	20
3	1	0.8	38.4	38.4	39.8	40.4	12.2	12.2	13.3	13.5	2
3	2	1.8	41.1	41.1	42.8	42.9	11.1	11.2	12.0	12.2	5
4	1	0.1	25.9	25.9	27.2	27.5	17.3	17.3	19.0	19.3	11
4	2	-2.4	25.4	26.4	25.9	26.3	18.3	18.4	20.0	20.3	12
5	1	6.8	40.7	40.7	41.5	42.2	9.6	12.0	7.8	11.0	10
5	2	7.1	36.3	36.4	37.6	38.2	12.3	15.3	10.2	14.5	13
6	1	17.4	34.3	34.6	45.8	46.0	25.6	31.8	26.0	28.0	25
6	2	21.3	40.3	40.3	43.3	43.4	25.6	31.9	24.5	24.9	30
7	1	23.2	15.1	17.6	20.8	21.9	3.8	4.7	3.2	4.5	22
7	2	22.8	14.5	16.9	19.5	23.3	13.0	16.1	10.6	15.1	26
8	1	31.0	28.8	28.8	27.5	28.0	3.4	4.7	6.3	6.7	38
8	2	39.7	40.7	47.3	38.0	47.2	5.9	7.3	7.0	7.1	37
9	1	19.9	37.4	38.7	42.5	42.6	16.6	20.7	14.4	20.5	18
9	2	23.5	45.5	47.1	51.2	51.4	18.7	23.3	16.5	23.5	22
10	1	1.7	31.8	31.8	38.3	38.4	45.5	45.6	47.4	48.2	25
10	2	3.1	29.5	30.4	33.5	33.6	24.0	29.8	21.0	29.9	-2
11	1	5.3	23.1	23.9	26.4	27.8	21.8	27.1	20.9	29.7	16
11	2	7.3	23.8	27.6	26.9	28.4	21.3	21.4	26.1	26.6	25
12	1	16.1	30.9	32.0	35.8	35.9	34.3	34.4	38.0	38.6	21
12	2	18.3	28.7	29.6	31.3	31.4	21.6	30.0	36.4	38.8	37
13	1	22.4	32.1	33.2	36.0	36.1	2.9	4.0	7.4	7.9	21
13	2	24.9	27.9	28.9	31.3	31.4	2.4	3.3	6.7	7.2	28
14	1	11.5	53.5	55.7	50.1	54.6	25.2	25.3	29.3	29.8	26
14	2	13.7	51.3	51.3	49.2	50.0	27.1	27.2	32.2	32.8	30
15	1	-4.1	38.2	38.2	36.0	36.6	20.3	20.4	25.5	25.9	16
15	2	-2.8	39.0	39.0	37.3	37.9	17.3	17.3	19.9	20.2	13
16	1	12.7	50.5	50.5	51.8	52.6	20.3	20.4	19.4	19.7	15
16	2	11.8	59.9	59.9	61.2	61.3	33.2	33.4	33.4	34.0	20
17	1	12.5	60.7	60.7	59.6	60.5	35.9	36.0	39.9	40.6	49
17	2	19.7	67.0	67.1	65.3	66.3	34.8	35.0	37.6	38.2	44
18	1	12.4	44.4	46.0	51.2	51.3	1.8	2.0	2.0	2.0	10
18	2	11.7	45.7	47.3	52.9	53.1	23.2	23.3	22.3	22.7	16
19	1	15.3	37.3	37.9	48.6	48.8	13.1	13.2	16.3	17.5	23
19	2	15.4	37.2	37.8	49.4	49.5	13.1	13.2	15.4	16.5	21
20	1	5.8	22.1	22.1	22.3	22.4	17.6	21.9	16.4	23.4	17
20	2	7.0	22.0	22.0	22.8	22.8	19.1	19.2	20.9	21.2	19

Table A-7 – Males Standing Barefoot on a Surface Gradient of 30°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	27.7	24.8	24.8	23.4	23.8	14.9	18.6	12.9	18.4	37
1	2	32.5	24.5	25.5	23.1	25.1	17.1	21.2	15.4	21.9	41
2	1	15.4	36.7	38.2	33.9	36.9	13.0	13.1	19.9	21.1	22
2	2	10.2	28.4	40.3	25.5	39.3	15.2	15.3	19.5	19.8	23
3	1	3.6	32.3	33.6	31.3	33.9	15.1	15.2	18.1	18.4	13
3	2	3.3	41.1	41.1	40.6	41.2	13.2	13.3	14.3	14.5	8
4	1	-0.2	24.2	24.2	25.0	25.4	19.3	19.4	21.9	22.3	14
4	2	0.9	26.5	26.5	27.7	28.1	18.2	18.3	21.2	21.5	16
5	1	10.5	42.1	43.9	42.1	42.7	7.1	8.1	8.1	8.1	6
5	2	7.3	40.3	42.0	40.1	40.7	9.1	11.3	7.1	10.1	12
6	1	26.5	33.5	33.5	36.4	36.5	23.4	29.1	23.7	24.1	32
6	2	32.4	35.3	36.5	39.9	40.0	21.3	26.5	21.4	21.8	36
7	1	62.5	6.0	14.9	12.6	19.0	17.1	17.2	21.4	21.7	41
7	2	70.4	15.8	22.2	12.7	19.4	22.2	22.3	28.6	30.5	43
8	1	62.6	26.4	30.6	24.4	26.5	26.1	26.2	29.9	30.4	51
8	2	59.2	23.3	27.0	21.1	26.2	17.2	17.3	17.3	17.6	45
9	1	38.2	37.8	39.0	44.0	44.1	6.5	8.0	4.6	6.6	29
9	2	42.5	39.9	41.3	48.1	50.8	3.3	4.1	7.3	7.8	27
10	1	10.0	32.6	32.6	35.7	35.8	36.5	36.7	38.2	38.9	34
10	2	12.5	27.9	28.3	35.4	35.5	34.4	34.5	36.7	39.4	36
11	1	2.7	29.2	30.2	31.8	33.5	12.8	15.9	12.1	12.3	8
11	2	4.5	27.0	31.4	29.3	30.8	14.8	18.4	17.5	18.6	17
12	1	22.2	28.0	28.9	29.9	30.0	15.4	21.4	26.5	28.2	39
12	2	30.4	24.4	25.3	28.5	28.6	20.0	20.1	23.3	23.7	35
13	1	11.4	35.0	35.0	36.2	36.3	12.8	15.9	14.0	14.2	39
13	2	11.8	31.3	31.7	36.0	36.1	23.5	29.3	19.6	31.4	28
14	1	13.8	61.5	61.5	59.5	60.5	17.1	17.1	21.6	22.0	23
14	2	12.0	56.9	59.2	53.3	58.1	21.1	21.2	26.2	26.7	29
15	1	9.7	38.8	38.8	36.8	37.3	14.4	17.9	20.0	21.3	24
15	2	8.7	44.6	44.6	43.3	43.9	14.2	14.2	19.7	21.0	19
16	1	28.8	58.1	58.1	59.3	60.2	11.1	11.2	8.7	8.9	24
16	2	32.2	49.9	49.9	52.8	53.0	12.0	12.1	11.5	11.7	28
17	1	29.4	58.3	58.3	58.0	58.1	19.0	19.1	23.5	23.9	42
17	2	34.0	50.9	52.9	47.5	51.6	16.1	16.2	20.4	21.7	51
18	1	24.8	42.3	43.8	48.9	49.1	9.6	12.0	8.1	11.5	17
18	2	21.7	45.6	45.6	48.8	49.5	18.3	18.3	16.4	16.7	25
19	1	16.4	53.1	53.1	56.4	56.6	14.1	14.2	16.2	16.4	25
19	2	26.6	45.2	46.8	49.7	49.9	7.1	7.2	9.9	10.5	30
20	1	8.9	22.0	22.8	22.0	22.8	16.3	16.6	16.3	16.6	9
20	2	9.8	24.4	25.2	24.4	25.2	15.2	15.5	15.2	15.5	10

Table A-8 – Males Standing Barefoot on a Surface Gradient of -5°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	2.1	36.9	38.4	35.9	39.1	14.4	17.9	15.0	15.3	20
1	2	3.3	39.8	41.4	38.8	42.2	18.1	22.5	16.4	16.7	20
2	1	3.0	41.8	41.8	42.7	43.4	20.3	20.4	22.6	23.0	14
2	2	2.5	47.6	47.6	48.6	49.3	14.2	14.3	16.6	16.9	11
3	1	0.6	45.5	45.5	47.6	48.2	12.9	16.0	10.6	15.0	0
3	2	1.5	50.1	50.2	52.1	52.9	14.4	17.9	11.9	17.0	3
4	1	0.8	30.1	30.1	33.3	33.4	9.6	12.0	9.1	12.9	1
4	2	-1.4	34.2	34.2	37.2	37.7	6.4	7.0	7.1	7.1	8
5	1	2.6	40.8	40.8	42.2	42.8	12.8	15.9	10.2	14.5	12
5	2	6.7	38.3	38.3	39.3	39.9	15.0	18.6	11.0	15.6	12
6	1	5.4	42.3	42.3	46.6	46.8	20.3	20.4	21.3	21.7	12
6	2	5.0	47.1	48.7	51.3	51.5	23.4	23.5	25.3	25.8	14
7	1	2.0	33.4	33.4	36.4	36.9	16.0	19.9	12.3	17.6	5
7	2	2.9	35.9	37.1	41.9	42.0	15.5	19.2	12.3	17.5	3
8	1	1.3	53.1	55.4	52.4	53.3	31.2	31.4	36.3	36.9	22
8	2	4.0	64.9	67.7	63.4	69.2	22.2	22.3	24.8	25.2	18
9	1	0.5	42.1	43.8	48.8	48.9	14.5	18.0	11.0	15.6	1
9	2	2.2	46.3	46.3	53.3	53.5	11.2	11.2	8.8	12.5	0
10	1	0.7	35.4	36.7	40.6	40.7	15.7	15.8	15.8	16.1	8
10	2	-1.4	31.7	31.7	37.5	37.6	17.6	21.8	17.4	17.7	-14
11	1	0.8	37.2	38.5	40.9	43.1	9.2	10.0	8.4	10.7	7
11	2	2.3	42.4	43.9	46.1	46.3	17.0	21.2	19.3	19.6	14
12	1	5.9	38.9	38.9	42.8	42.9	29.4	29.5	33.2	33.8	12
12	2	5.8	42.9	42.9	46.1	46.2	30.3	30.4	37.3	39.7	16
13	1	-3.7	36.8	38.0	38.4	38.5	23.4	23.5	24.7	25.1	15
13	2	-1.7	38.8	38.8	39.4	39.9	21.3	21.4	22.3	22.7	17
14	1	6.6	66.5	66.6	66.3	67.4	28.3	28.4	30.8	31.3	17
14	2	6.8	70.1	70.2	69.6	70.8	28.3	28.5	30.8	31.4	19
15	1	-2.4	40.1	40.1	38.3	38.9	17.2	17.3	20.5	20.9	14
15	2	0.2	43.1	44.8	39.9	43.4	19.6	24.4	23.9	25.4	21
16	1	-0.3	50.3	52.4	50.2	54.8	36.3	36.5	35.8	36.4	12
16	2	0.9	57.0	59.4	57.0	57.9	40.2	40.4	40.3	41.1	14
17	1	3.3	61.8	61.8	60.4	61.3	57.2	57.5	60.9	62.0	35
17	2	0.6	58.0	60.3	57.0	62.0	47.4	47.6	51.8	52.8	28
18	1	11.3	54.6	56.4	60.4	60.6	23.5	29.3	21.7	30.9	18
18	2	10.7	48.6	50.4	57.3	57.6	16.3	16.3	17.0	17.3	15
19	1	6.7	60.2	62.3	66.5	66.7	8.3	9.0	9.1	9.1	10
19	2	5.7	61.5	63.7	68.0	68.3	13.7	15.0	12.6	16.0	13
20	1	-1.8	24.0	24.0	27.1	27.2	11.7	14.6	10.2	14.4	-1
20	2	-1.3	28.7	29.8	30.9	31.3	14.2	14.3	13.4	13.6	4

Table A-9 – Males Standing Barefoot on a Surface Gradient of -10°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	2.0	36.6	37.8	37.6	37.7	22.4	27.8	21.1	21.5	21
1	2	2.7	34.7	36.1	33.9	34.4	17.6	21.9	15.7	22.4	20
2	1	0.5	41.9	41.9	42.3	43.0	18.6	23.2	19.0	19.4	12
2	2	0.6	46.8	46.8	47.8	48.5	17.3	17.3	19.6	19.9	10
3	1	1.0	44.8	44.8	47.7	48.4	12.8	15.9	10.9	15.5	1
3	2	1.9	46.1	46.1	48.4	49.0	9.6	12.0	7.8	11.0	1
4	1	-0.2	29.3	30.3	32.8	32.9	6.4	7.0	5.8	7.3	6
4	2	-2.0	26.7	26.7	29.1	29.2	18.6	23.2	17.8	18.1	10
5	1	3.9	34.7	34.7	36.1	36.2	12.3	15.3	9.2	13.1	7
5	2	7.8	42.8	42.8	43.3	44.0	17.1	21.3	12.7	18.1	16
6	1	5.5	39.4	39.4	44.8	47.2	16.5	20.5	17.4	17.7	12
6	2	6.8	45.2	45.2	49.6	49.8	22.4	22.5	24.6	25.1	22
7	1	1.9	35.7	35.7	40.9	41.0	8.5	10.6	6.3	9.0	-2
7	2	1.6	34.9	34.9	39.5	39.6	10.1	12.6	7.4	10.5	2
8	1	-0.9	47.6	55.5	47.2	48.0	30.1	30.2	32.6	33.1	18
8	2	0.1	55.4	57.7	54.0	58.9	31.3	31.4	36.0	36.6	20
9	1	0.8	47.3	47.4	54.4	54.6	16.2	16.2	16.3	16.6	3
9	2	0.2	48.6	50.2	55.4	55.6	17.1	21.3	13.4	19.1	-3
10	1	-2.2	38.3	39.6	43.8	43.9	43.1	53.8	40.2	41.0	15
10	2	-3.7	37.4	43.6	44.7	47.1	16.6	16.7	18.8	20.0	18
11	1	2.0	42.2	43.6	46.5	46.7	17.2	17.3	19.5	19.9	11
11	2	-0.4	42.4	43.8	46.3	46.4	18.3	18.4	20.9	21.3	10
12	1	1.5	39.0	39.0	40.6	41.1	42.8	43.0	47.1	47.9	19
12	2	3.5	39.9	41.3	44.4	44.6	36.8	37.0	44.7	45.4	22
13	1	-2.0	35.9	35.9	37.3	37.4	18.2	18.3	19.3	19.6	8
13	2	1.2	36.6	37.8	40.1	40.2	8.1	8.2	10.8	11.5	0
14	1	5.6	65.1	65.1	65.0	66.0	26.2	26.4	29.4	29.9	17
14	2	6.0	65.8	65.8	65.7	66.7	28.3	28.4	31.8	32.3	18
15	1	-4.7	42.9	42.9	42.5	43.1	21.3	21.4	25.8	26.3	8
15	2	-4.2	44.1	44.1	43.8	44.4	18.3	18.4	21.6	21.9	7
16	1	-1.1	49.8	51.9	50.1	50.9	30.4	30.5	33.2	33.7	7
16	2	-0.3	64.1	67.0	63.4	69.6	12.5	14.2	9.3	9.3	6
17	1	5.6	71.1	71.1	71.6	72.7	41.4	41.5	45.6	46.4	25
17	2	3.8	57.4	59.6	56.2	57.1	40.2	40.4	45.1	45.9	34
18	1	5.8	51.3	53.2	61.2	64.7	28.2	35.1	26.5	27.0	12
18	2	6.0	54.6	54.6	61.4	61.6	26.6	33.1	22.9	23.3	11
19	1	5.8	63.0	65.2	69.8	70.0	20.8	25.9	21.4	21.8	17
19	2	6.7	68.2	70.6	73.8	74.0	19.7	24.5	17.8	25.4	14
20	1	-2.4	29.9	31.1	31.4	31.9	17.1	17.2	18.2	18.5	5
20	2	-4.0	26.3	26.3	29.4	29.4	19.2	19.2	19.2	19.6	5

Table A-10 – Males Standing Barefoot on a Surface Gradient of -15°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	2.3	36.7	38.2	37.2	37.8	14.9	18.5	15.0	15.3	18
1	2	2.5	37.1	38.6	36.7	37.2	17.5	21.8	17.4	17.7	19
2	1	-0.8	43.6	43.6	45.4	46.0	11.0	12.0	12.2	12.2	8
2	2	-0.8	49.7	49.7	50.4	51.1	21.3	21.3	24.2	24.6	11
3	1	-0.4	44.9	44.9	47.4	47.5	10.1	12.6	8.1	11.5	-3
3	2	-0.1	45.4	45.4	48.3	48.9	13.9	17.3	11.6	16.5	1
4	1	-0.5	27.5	28.5	29.9	30.0	13.3	16.5	13.4	13.6	7
4	2	-1.1	32.7	37.9	32.9	35.8	12.8	16.0	11.5	16.4	5
5	1	3.3	31.9	33.0	33.9	34.0	10.2	12.6	7.8	11.0	7
5	2	4.7	42.4	42.4	44.4	45.1	11.8	14.6	9.2	13.0	6
6	1	5.6	48.4	48.4	53.2	53.3	22.4	22.5	24.0	24.4	18
6	2	7.0	47.9	47.9	51.6	51.7	19.2	23.8	19.1	19.4	17
7	1	3.4	30.3	30.3	37.0	37.1	9.7	12.0	7.6	12.7	-3
7	2	2.5	37.3	38.5	43.5	45.8	13.4	16.6	9.9	14.1	1
8	1	0.3	65.2	68.1	64.4	65.5	28.4	28.5	27.1	27.5	6
8	2	0.1	49.8	51.8	49.7	50.5	30.2	30.3	29.5	30.0	7
9	1	4.8	48.7	48.7	54.6	54.8	10.2	10.2	8.1	8.2	-5
9	2	3.8	47.4	48.9	55.8	56.0	10.7	13.3	8.8	12.5	-2
10	1	3.2	40.0	41.4	46.5	49.0	47.7	47.9	51.4	52.4	19
10	2	0.1	47.5	49.1	52.3	52.4	63.5	63.8	69.0	70.3	26
11	1	1.6	38.8	40.1	42.3	42.4	13.9	17.2	12.6	17.9	8
11	2	0.0	38.8	40.1	43.9	46.3	8.9	10.1	10.1	10.1	8
12	1	3.9	41.4	41.4	43.1	43.6	30.8	31.0	36.5	37.1	18
12	2	4.8	39.7	39.7	43.5	43.6	35.5	35.6	37.2	37.9	13
13	1	0.0	35.2	35.2	37.6	37.8	10.1	12.6	9.7	9.9	4
13	2	1.5	36.3	37.6	39.8	40.0	8.0	10.0	8.7	8.8	4
14	1	5.5	66.7	66.8	66.4	67.4	25.3	25.4	28.8	29.3	18
14	2	6.7	66.7	66.7	65.8	66.8	26.3	26.4	29.4	29.9	19
15	1	-3.2	40.2	40.2	38.9	39.5	18.2	18.3	22.1	22.5	14
15	2	-3.7	43.8	45.6	41.9	45.6	15.2	15.3	18.8	19.2	1
16	1	-3.7	50.1	50.1	50.0	50.8	36.6	36.7	35.4	36.0	12
16	2	-2.6	51.9	51.9	52.1	52.9	17.8	20.2	20.2	20.2	9
17	1	2.3	56.2	58.5	54.4	59.2	35.3	35.5	39.0	39.7	11
17	2	2.8	71.5	71.5	72.5	73.6	47.4	47.6	50.9	51.8	12
18	1	5.1	66.2	68.6	73.8	74.1	28.4	28.5	27.7	28.2	13
18	2	6.0	61.7	61.7	69.0	69.2	27.1	33.8	23.9	24.3	10
19	1	5.7	66.3	68.6	73.3	73.5	22.4	22.5	24.0	24.4	16
19	2	7.0	60.2	62.3	66.4	66.6	25.4	25.5	25.3	25.8	14
20	1	-2.1	30.0	31.2	31.5	31.9	12.8	15.9	14.6	14.9	5
20	2	-5.0	29.0	30.1	29.8	30.2	14.4	17.9	13.7	14.0	1

Table A-11 – Males Standing Barefoot on a Surface Gradient of -20°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	-0.1	37.3	43.4	35.2	43.7	22.9	28.5	21.1	21.5	19
1	2	-0.7	36.7	42.7	35.3	38.4	16.0	20.0	15.4	21.9	16
2	1	-2.0	44.7	46.5	44.6	48.6	20.3	20.4	23.5	23.9	9
2	2	0.8	51.0	51.0	51.2	52.0	25.4	25.5	27.3	27.8	13
3	1	-2.0	48.3	49.9	51.6	51.8	14.9	18.6	13.6	19.4	1
3	2	-2.3	46.2	46.2	49.0	49.1	14.9	18.6	13.6	19.4	2
4	1	-0.9	23.3	27.0	24.2	24.3	2.8	3.0	4.0	4.0	8
4	2	-1.0	26.7	31.0	27.8	30.2	11.7	14.6	11.4	11.6	5
5	1	6.0	38.6	38.6	39.8	40.4	3.6	4.0	4.8	6.6	9
5	2	5.0	45.7	45.7	47.0	47.7	10.2	12.6	7.8	11.0	10
6	1	5.2	43.0	43.0	46.0	46.1	20.3	20.4	21.7	22.1	18
6	2	7.4	47.8	49.5	53.0	53.2	27.5	27.6	29.3	29.9	20
7	1	1.2	35.9	35.9	40.4	40.5	17.1	21.2	13.7	19.5	6
7	2	2.7	38.0	39.3	44.1	44.3	19.2	23.9	15.5	22.0	5
8	1	-0.1	55.9	65.5	53.6	58.8	35.4	35.6	40.1	40.7	21
8	2	0.6	56.5	58.8	57.4	58.4	31.1	31.3	31.4	31.9	9
9	1	4.5	36.7	37.9	44.5	46.9	5.3	6.6	5.3	8.8	-8
9	2	3.5	47.5	49.0	55.4	55.6	14.4	18.0	12.3	17.5	-3
10	1	2.2	40.5	41.9	48.8	51.5	26.3	26.4	27.9	28.4	18
10	2	1.3	42.9	44.4	49.4	49.6	39.6	39.8	42.6	43.4	25
11	1	-0.2	43.1	44.6	49.3	52.0	19.3	19.4	21.3	21.7	7
11	2	1.2	37.0	43.1	44.0	46.5	30.3	30.4	33.4	34.0	11
12	1	5.6	44.7	44.7	45.9	46.6	35.9	36.0	42.5	43.2	22
12	2	7.2	42.0	42.0	45.7	45.8	40.4	40.6	42.7	43.5	13
13	1	0.4	34.2	35.3	38.6	38.7	7.1	7.1	9.2	9.4	-1
13	2	1.3	39.6	40.9	41.7	41.8	17.2	17.3	19.2	19.6	25
14	1	5.9	64.4	64.4	63.8	64.8	24.3	24.4	28.5	29.0	19
14	2	7.4	68.4	68.4	68.2	69.3	28.3	28.4	32.0	32.6	20
15	1	-2.5	45.0	45.0	44.3	45.0	20.4	20.5	23.6	24.0	3
15	2	0.0	45.3	47.1	43.0	43.7	17.1	17.1	20.3	20.7	9
16	1	-3.1	50.8	52.8	54.8	54.9	28.2	28.4	34.6	35.2	10
16	2	-2.1	49.0	51.0	49.3	49.4	25.4	25.5	26.0	26.5	4
17	1	3.9	67.5	67.5	68.9	70.0	35.4	35.6	41.3	42.1	8
17	2	2.0	65.2	67.8	64.8	65.8	49.4	49.6	51.6	52.5	15
18	1	6.7	58.0	60.0	66.8	67.0	28.7	35.7	26.5	27.0	11
18	2	4.5	58.5	58.5	63.0	63.8	25.3	25.4	23.1	23.5	11
19	1	1.7	52.4	54.2	57.9	58.1	19.3	19.4	20.0	20.4	10
19	2	6.2	50.6	52.3	56.5	56.6	16.5	20.5	15.4	15.7	11
20	1	-2.1	27.7	28.7	29.8	29.8	8.2	9.0	8.4	10.6	7
20	2	-2.8	23.7	27.5	26.9	28.4	16.3	16.3	17.7	18.0	9

Table A-12 – Males Standing Barefoot on a Surface Gradient of -25°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	0.8	33.0	38.4	30.9	31.4	23.4	29.1	21.8	22.2	21
1	2	0.8	32.6	34.0	31.0	33.7	22.4	22.5	22.1	22.5	20
2	1	-0.8	45.6	47.4	45.4	49.4	20.3	20.4	23.9	24.3	12
2	2	-0.1	51.6	51.6	52.8	53.6	23.3	23.4	26.8	27.3	12
3	1	-0.5	40.8	40.8	42.9	43.0	14.4	17.9	12.3	17.4	2
3	2	1.5	46.5	48.0	50.1	50.2	14.4	17.9	12.6	18.0	3
4	1	-1.9	28.0	29.1	29.0	29.4	14.4	17.9	13.7	14.0	5
4	2	-1.6	26.1	30.2	27.3	27.6	13.2	13.3	14.3	14.5	5
5	1	7.6	46.8	46.8	48.5	48.6	6.0	7.4	6.6	7.0	3
5	2	2.8	32.7	32.7	33.8	34.2	21.8	27.2	17.6	25.0	16
6	1	9.4	45.6	45.6	50.2	50.3	20.2	25.2	19.4	19.8	17
6	2	6.7	46.9	46.9	50.9	51.0	21.3	26.5	21.4	21.8	17
7	1	1.4	28.2	29.3	31.5	31.6	11.2	13.9	8.8	12.5	5
7	2	2.7	28.9	28.9	34.1	35.9	17.1	21.2	13.4	19.0	9
8	1	2.4	56.2	58.7	55.3	60.5	30.2	30.3	35.7	38.0	22
8	2	1.0	57.3	59.7	57.6	58.5	28.4	28.5	28.0	28.5	7
9	1	3.9	51.1	51.1	58.9	59.1	16.2	16.3	14.1	14.3	0
9	2	3.9	56.4	56.4	63.6	63.8	15.2	15.3	14.7	15.0	2
10	1	-0.9	42.5	43.9	51.2	54.0	26.2	26.3	28.0	28.5	18
10	2	-1.6	42.6	44.0	48.4	48.5	36.6	36.8	40.2	41.0	17
11	1	1.1	42.4	43.9	46.3	46.4	13.4	16.6	11.9	16.9	2
11	2	1.1	43.2	44.7	47.9	48.0	15.3	15.3	15.4	15.6	4
12	1	4.1	36.9	36.9	40.9	41.0	36.4	36.5	42.0	42.7	13
12	2	7.3	38.8	38.9	40.9	41.0	28.8	29.0	35.5	36.1	24
13	1	-0.7	37.9	37.9	41.0	41.1	8.1	8.1	9.9	10.1	3
13	2	-0.9	35.9	35.9	38.1	38.2	12.8	15.9	13.4	13.6	6
14	1	5.9	64.5	64.5	63.2	64.2	30.4	30.5	35.1	35.7	23
14	2	6.4	68.2	68.2	67.1	68.1	26.5	33.0	31.0	33.0	24
15	1	0.6	42.7	44.4	41.0	41.6	19.3	19.4	23.9	24.3	17
15	2	-3.3	38.7	38.7	39.8	39.9	16.2	16.3	21.1	21.5	13
16	1	-4.0	45.6	45.6	46.5	47.2	30.4	30.5	32.5	33.1	11
16	2	-2.0	46.1	46.1	47.5	48.2	24.6	30.6	22.0	31.4	2
17	1	3.6	75.4	75.4	75.2	76.4	48.7	48.9	52.1	53.1	3
17	2	1.1	61.4	61.4	60.7	61.6	41.4	41.6	46.0	46.8	26
18	1	8.3	58.4	60.4	65.9	66.1	33.6	33.7	32.5	33.1	17
18	2	2.7	56.3	58.5	57.7	62.6	36.7	45.7	32.9	33.5	19
19	1	3.8	49.3	51.0	54.7	54.9	21.8	27.1	23.4	23.8	19
19	2	4.4	45.2	46.7	49.5	49.7	20.2	25.2	20.1	20.4	18
20	1	-3.6	22.4	23.1	24.7	24.8	14.2	14.3	15.3	15.6	7
20	2	-1.3	28.2	29.1	32.8	34.5	12.2	12.2	13.0	13.2	6

Table A-13 – Males Standing Barefoot on a Surface Gradient of -30°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
1	1	3.3	34.6	36.0	35.0	35.6	17.0	21.2	16.1	16.4	17
1	2	0.8	31.2	32.4	29.9	32.6	24.5	30.5	21.7	30.9	17
2	1	-2.7	44.8	46.6	46.5	46.6	11.0	12.0	18.0	18.1	6
2	2	-0.4	44.4	46.2	44.1	47.9	20.2	20.3	23.8	24.2	9
3	1	0.2	43.5	43.5	45.8	46.5	17.1	21.2	14.7	20.9	7
3	2	-0.3	41.3	41.3	43.7	43.8	13.3	16.6	11.6	16.4	1
4	1	-1.1	27.1	31.4	26.9	33.3	14.4	17.9	14.4	14.6	9
4	2	-1.3	27.8	28.9	29.0	29.1	19.2	23.9	17.8	25.4	10
5	1	5.1	46.2	46.2	47.9	48.7	10.7	13.3	8.5	12.0	11
5	2	4.0	44.9	44.9	46.0	46.7	9.6	12.0	6.7	9.6	6
6	1	7.8	43.2	43.2	47.5	47.6	20.3	20.4	20.4	20.7	15
6	2	7.6	48.8	48.8	52.5	52.6	19.2	23.8	18.4	18.7	14
7	1	2.4	31.2	32.3	38.4	40.5	16.5	20.5	14.8	15.1	9
7	2	5.8	34.2	35.4	39.0	39.1	20.8	25.8	17.5	24.9	14
8	1	1.6	52.5	54.8	50.8	55.6	26.3	26.4	31.0	31.6	18
8	2	0.4	54.7	57.0	54.3	59.4	24.3	24.4	24.9	25.3	6
9	1	4.5	49.2	51.2	55.8	55.9	14.4	17.9	12.6	17.9	3
9	2	1.9	48.7	48.7	54.2	54.3	12.2	12.2	11.1	11.2	3
10	1	3.1	48.9	50.6	55.1	55.3	41.7	41.8	42.3	43.1	23
10	2	-2.4	34.6	35.7	41.1	41.2	37.4	37.5	40.4	41.1	24
11	1	-0.8	37.5	43.7	44.8	47.3	11.7	14.6	10.5	14.9	-2
11	2	0.4	38.3	39.6	44.0	46.4	13.4	16.6	11.9	16.9	1
12	1	6.9	42.8	42.8	43.8	44.0	30.8	31.0	44.3	47.2	25
12	2	4.7	42.1	42.1	44.2	44.3	32.8	33.0	40.5	43.1	23
13	1	3.3	35.8	35.8	39.6	39.7	6.4	8.0	8.9	9.1	2
13	2	0.2	36.8	36.8	38.6	38.7	11.7	14.6	12.7	12.9	7
14	1	4.4	66.3	66.3	67.3	68.3	24.3	24.4	29.4	29.9	17
14	2	5.3	65.2	65.2	65.4	66.4	25.1	25.2	28.9	29.4	16
15	1	1.2	38.2	39.7	35.9	39.0	18.1	22.5	19.1	20.3	15
15	2	-0.8	42.4	44.1	39.6	43.0	21.4	21.5	24.3	24.7	13
16	1	-2.6	45.7	53.2	47.1	47.1	24.2	24.3	27.1	27.6	8
16	2	-1.5	46.4	48.3	46.1	50.4	22.1	22.2	22.2	22.6	0
17	1	2.5	70.4	70.4	71.4	72.5	47.4	47.6	50.9	51.8	23
17	2	3.0	70.2	70.2	69.4	70.4	37.9	38.0	40.5	41.2	5
18	1	7.1	56.5	58.5	63.6	63.8	30.5	30.6	31.7	32.3	21
18	2	4.4	51.5	51.5	56.0	56.2	21.3	26.5	18.2	25.9	11
19	1	2.4	40.2	41.6	43.4	43.5	17.2	17.3	19.9	20.2	19
19	2	4.7	39.8	41.1	43.0	43.1	15.2	15.3	16.9	17.2	19
20	1	-1.9	23.6	24.4	27.3	28.7	12.2	12.3	14.3	14.5	4
20	2	-1.5	28.7	28.7	31.9	32.0	13.1	13.2	13.9	14.2	1

Table B-1 – Females Standing Barefoot on a Surface Gradient of 0°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.8	54.3	54.3	54.0	54.8	24.3	24.4	27.5	27.9	18
21	2	2.5	52.8	54.9	50.2	54.6	26.5	26.6	30.2	30.8	26
22	1	10.3	54.7	56.6	61.8	62.0	18.2	18.2	19.8	20.2	13
22	2	11.2	59.0	59.0	61.1	61.2	32.5	40.5	30.3	43.2	20
23	1	7.6	50.4	50.4	49.5	50.2	47.3	59.0	47.7	48.7	46
23	2	5.1	61.6	61.6	59.4	59.5	32.6	32.7	35.0	35.6	13
24	1	-0.3	36.6	36.6	38.8	39.3	15.5	19.2	13.3	18.9	13
24	2	2.0	34.1	34.1	38.0	38.1	14.2	14.3	17.3	18.4	16
25	1	1.9	34.6	40.3	41.1	43.4	28.4	28.5	31.5	32.0	2
25	2	6.1	42.4	49.4	46.4	48.9	31.6	31.7	32.1	32.7	8
26	1	5.3	31.6	31.6	30.7	32.4	38.5	38.7	42.5	43.2	20
26	2	1.5	23.1	26.9	22.6	23.8	40.5	50.6	37.9	54.2	19
27	1	-1.0	41.2	41.2	43.3	43.9	17.2	17.2	22.0	23.4	6
27	2	-5.0	29.3	29.3	34.2	34.7	18.2	18.2	27.8	28.3	8
28	1	3.3	66.8	66.8	68.2	69.2	48.4	48.7	53.5	54.5	24
28	2	4.1	65.6	65.7	67.7	67.8	52.5	52.8	56.3	57.3	24
29	1	2.6	41.8	41.8	46.3	46.4	27.7	34.4	21.8	31.0	4
29	2	7.4	44.3	44.3	44.2	44.8	28.7	35.8	32.3	32.9	15
30	1	3.2	28.8	29.9	27.5	29.9	25.0	25.2	34.0	34.6	23
30	2	1.0	33.5	33.5	33.3	33.7	38.2	38.3	44.1	44.8	24
31	1	-2.6	39.2	40.6	36.2	36.3	24.2	24.3	29.3	31.2	32
31	2	-1.8	33.4	34.5	33.9	34.0	16.9	23.4	30.2	32.1	22
32	1	7.5	48.3	48.3	47.6	48.3	44.8	44.9	48.6	49.5	25
32	2	5.3	56.7	59.0	55.1	60.1	16.0	20.0	19.6	19.9	22
33	1	2.4	32.3	32.3	32.8	32.9	28.2	35.1	29.7	30.2	21
33	2	6.3	29.5	29.5	31.2	31.3	26.3	26.4	28.2	28.6	22
34	1	2.0	23.3	23.3	26.0	26.3	18.0	18.1	22.6	23.0	18
34	2	1.9	27.8	28.8	30.5	30.9	23.0	23.1	28.5	29.0	16
35	1	14.9	70.1	70.1	68.2	69.2	53.7	67.1	53.7	54.8	71
35	2	13.2	63.6	63.6	65.9	66.8	25.2	25.3	32.1	34.2	18
36	1	3.0	48.0	48.0	57.5	57.7	32.4	32.5	41.9	42.5	17
36	2	2.6	37.6	37.6	47.9	48.1	28.4	28.5	36.0	36.6	14
37	1	3.8	63.6	65.9	67.1	67.4	37.2	46.4	41.0	41.7	14
37	2	-1.6	54.2	63.8	65.8	69.7	19.1	19.2	22.7	23.1	-24
38	1	-1.9	50.7	52.3	52.8	52.9	18.6	23.2	17.1	17.4	9
38	2	-0.2	48.5	50.1	49.6	49.7	22.4	27.9	18.9	27.0	9
39	1	3.9	54.5	54.5	52.2	53.0	37.3	37.5	42.9	43.7	36
39	2	-2.2	53.5	55.7	52.1	52.9	13.4	18.5	20.2	21.5	18

Table B-2 – Females Standing Barefoot on a Surface Gradient of 5°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	3.8	56.3	56.3	55.5	56.2	23.2	23.3	27.7	28.2	16
21	2	3.5	54.0	54.0	52.2	52.9	34.0	42.4	38.6	39.3	28
22	1	11.0	55.4	55.4	59.2	60.0	25.3	25.4	28.8	29.3	22
22	2	11.0	47.6	49.3	56.5	56.7	9.8	11.1	7.2	7.2	0
23	1	4.9	57.1	57.1	53.5	54.2	21.2	21.3	26.0	26.5	12
23	2	8.4	60.2	60.3	59.9	60.0	23.2	23.3	25.2	25.6	19
24	1	1.9	45.8	45.8	46.3	46.5	42.1	42.3	46.6	47.4	19
24	2	5.0	42.0	42.0	40.5	41.1	22.8	31.6	35.1	37.4	24
25	1	1.6	34.6	35.8	37.7	37.8	34.1	34.2	36.2	36.8	3
25	2	0.0	37.8	39.1	38.9	39.0	25.6	25.7	33.0	35.1	20
26	1	2.1	27.5	27.5	23.9	24.2	26.2	26.3	31.5	32.1	14
26	2	2.7	27.2	27.2	25.2	25.6	27.2	27.4	34.2	34.8	14
27	1	-3.8	25.2	26.0	32.2	32.3	18.2	18.3	26.9	28.7	2
27	2	0.2	33.0	33.0	37.3	37.8	16.2	16.3	21.4	21.8	8
28	1	1.9	57.7	57.7	56.5	57.2	49.6	49.8	53.3	54.3	30
28	2	2.3	60.6	60.6	66.5	66.7	28.2	28.3	35.8	36.4	22
29	1	7.7	51.0	51.0	51.5	52.3	45.6	45.8	50.4	51.3	17
29	2	4.9	50.2	52.0	55.7	55.9	29.2	36.4	22.8	32.5	12
30	1	6.2	40.4	41.9	36.0	39.1	25.6	35.5	37.9	40.4	25
30	2	5.9	20.8	24.1	18.9	23.4	26.9	37.3	38.7	41.2	25
31	1	-2.9	40.5	41.9	40.3	40.4	24.2	24.3	30.2	32.2	4
31	2	-4.3	44.2	45.6	43.0	43.1	12.4	17.1	20.7	22.0	19
32	1	6.6	49.2	51.2	47.9	52.2	24.0	29.9	27.9	28.4	21
32	2	4.0	63.9	64.0	65.4	66.5	16.0	16.1	21.2	22.6	11
33	1	5.6	39.1	39.1	40.0	40.5	14.2	19.7	18.5	19.7	22
33	2	7.9	35.8	37.2	37.4	37.9	21.1	21.2	24.0	24.4	22
34	1	3.6	26.6	26.6	28.3	28.7	24.0	29.8	25.7	26.2	14
34	2	0.4	32.9	32.9	35.3	35.7	30.7	38.3	29.1	41.5	14
35	1	10.9	49.4	57.2	57.8	58.0	30.4	30.5	32.9	33.5	7
35	2	9.7	67.1	67.1	71.2	71.4	33.2	33.3	38.9	41.4	23
36	1	2.8	41.0	41.0	49.9	50.0	34.4	34.6	42.6	43.3	17
36	2	1.9	36.7	36.7	44.9	45.0	32.4	32.5	40.0	40.6	14
37	1	1.2	51.1	52.9	57.1	57.2	16.1	16.2	21.3	22.7	-5
37	2	0.6	55.1	57.0	59.8	60.0	16.5	18.1	23.2	23.2	55
38	1	-7.3	43.7	45.2	45.8	45.9	14.7	16.0	12.6	16.0	13
38	2	-5.9	38.1	38.1	39.3	39.8	30.3	37.7	28.8	29.3	18
39	1	3.2	47.5	49.4	43.4	47.2	37.5	37.7	43.4	44.1	47
39	2	4.4	50.0	52.1	47.5	48.2	34.9	35.1	37.4	38.0	59

Table B-3 – Females Standing Barefoot on a Surface Gradient of 10°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	6.0	50.4	52.4	46.7	50.7	57.3	71.6	58.7	59.9	36
21	2	5.2	56.4	56.4	54.2	55.0	44.7	55.7	44.5	45.3	36
22	1	13.5	55.1	57.0	62.8	63.0	15.4	19.1	23.6	25.1	16
22	2	16.8	41.9	43.3	51.5	51.6	11.8	14.7	10.2	14.5	1
23	1	7.6	57.8	57.8	58.4	59.3	26.1	26.3	29.6	30.1	34
23	2	8.1	63.4	63.4	61.3	61.4	19.1	19.2	20.5	20.8	22
24	1	1.5	40.7	40.7	40.8	41.4	20.3	25.2	24.0	25.6	16
24	2	3.7	45.3	45.3	47.0	47.1	21.7	21.8	28.9	30.7	14
25	1	2.9	46.6	48.4	47.7	48.4	34.6	34.8	38.0	38.6	12
25	2	2.6	31.9	32.9	31.9	32.0	23.9	33.2	35.7	38.1	16
26	1	3.8	24.9	24.9	21.1	21.4	32.0	32.1	37.0	37.6	14
26	2	6.2	27.0	27.2	20.0	21.7	20.3	20.4	30.9	31.0	13
27	1	-3.0	45.8	45.8	51.9	52.1	19.3	19.4	26.1	26.5	3
27	2	-6.2	30.1	30.1	35.0	35.1	22.4	22.5	26.9	27.3	7
28	1	1.9	64.1	64.1	63.7	64.7	45.2	45.4	50.4	51.3	32
28	2	2.7	68.2	71.0	68.7	69.8	42.1	52.4	43.1	43.9	21
29	1	6.9	51.1	51.1	52.9	53.0	34.5	34.6	39.7	40.4	28
29	2	8.2	49.4	49.4	51.0	51.7	24.2	24.3	28.7	29.2	68
30	1	6.3	20.5	21.3	20.8	21.1	34.1	34.3	37.2	37.9	21
30	2	4.7	15.7	16.3	20.1	20.3	38.7	38.9	46.8	47.6	18
31	1	-6.4	46.0	53.5	46.7	49.2	31.5	39.2	30.2	30.7	-11
31	2	0.5	47.3	48.9	45.0	45.1	39.4	49.1	43.0	43.8	21
32	1	8.4	49.6	51.6	47.2	51.4	31.1	31.3	33.3	33.9	22
32	2	7.5	59.9	59.9	60.7	61.7	50.0	62.6	47.1	67.7	18
33	1	4.2	43.5	43.5	45.8	45.9	30.4	30.6	34.2	34.8	24
33	2	4.9	38.8	40.3	38.3	41.6	35.6	35.8	36.4	37.0	24
34	1	1.7	42.1	42.1	42.1	42.6	33.2	33.3	35.6	36.3	18
34	2	2.7	35.9	35.9	37.4	37.9	23.1	23.2	26.9	27.4	15
35	1	11.3	55.2	55.2	57.5	58.3	24.8	24.9	33.7	35.9	21
35	2	11.0	54.5	54.5	55.8	56.6	27.3	27.4	36.8	39.2	23
36	1	12.0	35.1	35.1	45.3	45.4	34.3	34.5	44.8	45.5	26
36	2	11.7	36.4	36.4	48.2	50.9	33.4	33.5	43.8	44.5	27
37	1	1.5	51.2	53.0	55.8	55.9	14.8	14.9	21.3	22.7	13
37	2	2.2	46.0	47.6	50.8	50.9	12.7	12.8	18.1	19.3	13
38	1	-6.8	44.8	44.8	46.5	47.1	11.0	12.0	9.4	12.0	13
38	2	-10.1	44.4	45.9	46.3	46.4	25.4	25.5	26.0	26.5	13
39	1	1.0	35.0	36.4	32.1	34.9	32.6	40.6	34.4	36.5	38
39	2	3.9	33.0	34.3	29.7	32.3	39.2	39.4	44.1	44.9	34

Table B-4 – Females Standing Barefoot on a Surface Gradient of 15°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	6.6	52.3	52.3	50.7	51.4	20.3	20.4	22.6	23.0	6
21	2	10.2	47.9	47.9	46.1	46.7	41.4	41.5	44.3	45.1	45
22	1	19.5	50.5	52.3	50.5	52.3	15.8	16.1	15.8	16.1	-5
22	2	16.4	59.4	61.4	67.6	67.8	12.1	12.2	14.8	15.1	18
23	1	5.1	63.1	65.1	65.7	65.9	21.1	21.2	25.3	25.7	18
23	2	10.3	57.7	57.7	56.7	57.5	27.3	27.5	31.8	32.3	17
24	1	2.1	43.7	43.7	43.6	44.2	29.5	36.7	27.6	39.4	12
24	2	1.9	41.5	41.5	41.0	41.5	28.2	35.2	29.4	29.9	19
25	1	3.2	34.0	39.6	35.5	37.4	35.5	35.6	38.8	39.5	21
25	2	5.0	33.0	34.1	33.5	35.3	22.9	23.0	25.2	25.6	18
26	1	8.4	23.9	23.9	19.4	19.7	13.4	13.5	17.7	18.0	14
26	2	6.5	25.9	29.2	20.0	20.0	33.0	41.1	36.3	39.0	13
27	1	-3.3	43.6	43.7	48.4	49.1	25.4	25.5	30.8	31.3	8
27	2	-2.4	40.3	41.8	41.7	41.8	26.3	26.4	29.8	30.3	13
28	1	0.3	56.7	56.7	60.5	60.7	36.5	36.7	44.7	45.4	22
28	2	5.4	57.7	57.7	61.4	61.6	41.7	41.8	49.1	49.9	24
29	1	12.5	56.1	56.1	56.7	57.6	45.3	45.5	47.6	48.4	14
29	2	10.2	54.7	54.7	55.2	56.0	36.3	36.5	40.7	41.4	15
30	1	12.1	30.7	31.9	27.9	30.2	34.7	34.8	38.4	39.0	28
30	2	11.1	23.8	24.8	26.2	28.5	36.2	45.0	42.8	43.6	24
31	1	-3.9	51.2	51.2	46.2	46.8	28.0	38.9	39.3	41.9	86
31	2	-4.5	58.0	58.0	54.4	55.1	35.9	36.0	42.5	43.2	17
32	1	5.8	43.3	45.0	40.1	43.6	30.4	37.8	29.2	29.7	20
32	2	5.3	51.4	51.4	53.5	54.3	29.8	29.9	35.4	36.1	26
33	1	5.3	46.3	46.3	44.7	45.3	40.5	50.5	37.2	53.3	27
33	2	5.9	46.1	46.1	48.0	48.6	38.6	38.7	41.5	42.3	22
34	1	0.7	37.6	37.6	37.1	37.6	18.1	18.1	20.4	20.7	20
34	2	4.4	30.6	30.6	32.3	32.7	13.9	17.3	15.0	15.3	17
35	1	7.1	62.9	62.9	65.6	65.8	44.1	44.3	47.7	48.5	15
35	2	12.7	60.7	62.8	64.3	64.5	32.3	32.5	38.3	40.8	22
36	1	12.3	32.3	32.3	40.2	40.4	37.3	37.5	43.3	44.0	32
36	2	14.1	32.3	32.3	43.3	45.7	32.3	32.5	42.9	45.7	32
37	1	3.9	38.9	40.2	51.6	54.5	21.1	21.2	26.9	27.4	-15
37	2	5.9	49.2	51.0	55.5	55.7	17.0	17.1	24.0	25.6	7
38	1	-5.0	43.8	45.3	45.2	45.3	25.4	25.5	25.7	26.2	12
38	2	2.6	45.8	47.3	47.9	48.1	5.7	7.9	11.1	11.8	-6
39	1	1.8	37.7	37.7	34.6	35.2	20.3	20.4	27.7	28.2	44
39	2	5.4	32.9	34.2	28.6	31.1	33.6	41.9	36.0	36.7	49

Table B-5 – Females Standing Barefoot on a Surface Gradient of 20°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	22.6	37.3	37.3	34.0	34.5	25.1	25.2	28.4	30.2	61
21	2	23.6	40.4	40.4	38.6	39.2	31.4	31.5	35.1	35.7	53
22	1	39.9	54.3	56.3	67.0	70.9	9.2	12.7	8.3	8.8	11
22	2	38.7	44.8	46.3	55.7	55.9	13.3	16.6	11.5	11.7	5
23	1	6.0	51.0	51.0	52.2	52.3	27.5	27.6	32.5	33.1	29
23	2	7.1	64.4	64.4	61.8	62.0	20.3	20.4	23.5	23.9	27
24	1	1.7	42.8	42.8	42.7	45.0	41.8	52.2	38.4	55.0	32
24	2	4.9	37.8	37.8	37.8	38.3	33.5	41.8	36.0	36.7	29
25	1	12.6	25.4	26.2	27.3	28.8	33.0	41.1	32.1	32.7	16
25	2	12.2	26.6	27.5	26.3	27.7	16.6	16.7	24.3	25.9	26
26	1	13.1	22.1	22.9	19.0	19.0	27.2	33.8	30.9	31.5	16
26	2	13.3	17.9	17.9	15.3	15.5	21.9	22.0	26.5	26.9	20
27	1	-3.4	32.5	32.5	36.3	36.8	21.2	21.3	32.2	34.4	13
27	2	-0.1	33.3	33.3	32.1	32.5	20.3	20.4	23.5	23.9	16
28	1	12.9	45.6	46.3	54.2	54.3	38.3	38.5	45.7	45.9	26
28	2	5.9	42.1	42.1	38.6	39.2	14.4	19.9	25.1	26.8	19
29	1	7.3	59.6	59.6	59.7	60.6	48.5	48.7	54.5	55.5	20
29	2	7.7	45.0	45.0	46.1	46.7	24.3	24.4	29.4	29.9	47
30	1	22.5	15.8	18.2	16.6	16.8	20.5	28.4	33.0	35.2	36
30	2	22.8	35.7	37.1	33.3	36.2	28.0	28.1	30.5	31.0	34
31	1	9.4	23.3	23.5	17.2	18.6	23.3	23.4	49.2	49.4	57
31	2	17.2	25.1	26.0	24.1	24.2	24.5	30.5	32.5	34.6	50
32	1	2.6	50.8	50.8	53.1	53.9	41.5	51.8	44.0	44.8	18
32	2	5.3	50.6	52.6	52.1	52.9	40.7	40.9	48.4	49.3	21
33	1	6.5	35.2	35.2	34.8	35.2	35.7	44.4	32.4	46.2	25
33	2	5.7	42.9	42.9	42.3	42.9	39.5	39.7	43.1	43.9	20
34	1	11.4	21.2	21.9	27.9	28.0	19.5	24.2	13.7	19.4	20
34	2	18.3	47.2	48.8	44.9	45.0	16.4	20.4	14.9	21.2	32
35	1	13.4	57.8	57.8	58.5	59.3	26.3	26.4	37.4	39.8	24
35	2	15.1	53.3	55.0	63.3	63.5	41.3	41.5	46.8	47.6	15
36	1	31.0	42.9	44.4	48.2	48.3	35.5	35.7	41.1	41.8	54
36	2	28.5	38.2	39.5	46.3	46.5	27.2	27.3	36.1	38.5	42
37	1	18.6	45.9	47.4	45.6	45.8	17.0	17.1	20.6	21.0	42
37	2	25.2	60.0	62.1	62.7	62.9	16.8	16.9	21.7	22.1	55
38	1	11.3	47.5	49.1	51.4	51.5	11.2	13.9	10.1	14.4	11
38	2	11.1	41.3	46.5	50.8	50.9	7.5	9.3	5.1	8.1	7
39	1	24.6	44.4	44.4	42.7	43.4	11.1	15.4	18.1	19.3	28
39	2	7.5	42.8	44.6	39.6	43.2	20.9	26.0	26.5	28.2	38

Table B-6 – Females Standing Barefoot on a Surface Gradient of 25°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	33.9	42.3	42.3	41.3	41.8	20.8	25.9	23.3	23.7	57
21	2	35.6	44.1	44.1	42.0	42.6	22.4	22.5	25.9	26.4	53
22	1	49.2	51.7	53.5	62.9	63.2	12.9	13.0	7.3	7.4	37
22	2	50.1	53.8	55.8	68.4	72.5	27.3	27.4	23.7	24.2	51
23	1	6.5	49.0	49.0	47.6	48.2	25.4	25.5	28.8	29.4	26
23	2	11.3	55.8	55.8	54.6	55.4	23.5	29.3	22.7	32.3	26
24	1	2.1	43.5	43.5	41.9	42.5	45.9	57.3	43.4	62.2	32
24	2	3.8	42.4	42.4	42.2	42.8	41.6	51.9	39.6	56.7	27
25	1	9.3	24.8	25.6	26.7	28.2	37.4	46.7	33.8	48.4	9
25	2	11.9	27.5	39.6	30.8	32.5	24.3	24.4	27.6	29.7	22
26	1	18.7	18.4	19.0	15.8	15.9	15.2	15.3	22.2	23.6	29
26	2	14.9	19.7	20.3	15.4	15.5	22.3	22.4	25.5	25.9	18
27	1	6.8	39.9	39.9	43.6	44.2	11.1	11.2	19.8	21.1	12
27	2	0.5	39.1	39.1	45.1	45.7	17.2	17.3	28.7	30.6	9
28	1	12.5	62.7	62.7	66.5	66.7	23.1	23.2	28.3	28.8	44
28	2	10.1	51.8	51.8	51.6	52.3	34.6	34.7	38.6	39.3	16
29	1	8.0	54.4	54.4	54.5	54.6	34.3	34.4	38.3	39.0	23
29	2	10.3	62.1	62.1	60.6	61.6	40.2	40.4	45.5	46.3	18
30	1	16.5	43.9	45.0	46.1	46.5	25.2	27.1	28.5	31.2	28
30	2	19.1	43.5	44.0	44.3	45.5	23.6	26.7	27.1	30.0	32
31	1	10.7	25.5	25.8	23.2	23.5	24.1	29.9	41.5	41.7	40
31	2	18.6	23.6	23.6	20.7	21.0	25.6	31.9	27.3	27.8	48
32	1	2.0	49.6	49.6	50.8	51.6	25.6	31.8	31.9	32.4	21
32	2	6.9	68.5	68.5	66.4	67.3	37.2	46.4	40.3	41.0	22
33	1	5.4	35.0	35.0	33.4	33.8	31.4	39.1	30.8	31.3	24
33	2	7.3	52.2	52.2	52.2	52.2	35.7	36.3	35.7	36.3	24
34	1	14.0	31.3	32.4	31.3	32.4	18.7	19.9	18.7	19.9	14
34	2	17.0	36.6	36.6	33.9	34.4	17.4	21.6	15.3	21.7	24
35	1	13.0	53.1	53.1	54.5	55.3	14.1	14.1	21.9	22.2	20
35	2	19.0	65.0	65.0	68.1	68.3	29.3	29.5	40.3	43.0	31
36	1	46.2	40.8	40.8	43.9	44.1	29.3	29.4	35.0	35.5	68
36	2	50.0	33.7	33.7	44.1	46.6	29.2	29.3	35.8	36.4	55
37	1	40.7	57.7	59.8	63.0	66.5	13.6	13.6	17.2	17.5	40
37	2	45.7	40.4	41.8	48.5	51.3	6.1	7.5	17.6	29.4	62
38	1	15.2	45.0	46.6	45.7	45.8	9.2	9.2	9.4	9.5	18
38	2	18.2	45.1	46.6	48.8	48.9	7.0	8.7	5.3	7.6	12
39	1	7.4	44.6	46.4	41.9	42.5	13.3	16.6	21.8	23.3	21
39	2	6.8	43.3	45.0	43.3	45.0	30.5	31.0	30.5	31.0	36

Table B-7 – Females Standing Barefoot on a Surface Gradient of 30°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1										
21	2										
22	1										
22	2										
23	1	13.8	43.0	43.0	42.7	42.8	16.2	16.3	22.3	23.7	31
23	2	16.8	59.0	59.0	60.9	61.1	19.2	19.2	23.7	24.1	15
24	1	0.0	54.4	54.4	54.7	54.9	31.4	31.5	37.1	37.7	15
24	2	2.4	43.7	43.8	42.6	43.2	20.6	25.5	30.6	32.5	33
25	1										
25	2										
26	1	16.8	21.6	21.6	18.0	18.2	15.3	15.4	18.3	18.6	22
26	2	14.6	29.1	30.1	26.2	26.3	28.3	28.4	33.0	33.6	17
27	1	13.2	43.4	45.2	51.2	51.3	14.1	14.1	29.9	32.0	18
27	2	21.1	39.7	43.4	46.8	47.5	12.1	12.2	21.4	25.3	23
28	1	24.5	43.8	44.4	51.7	51.8	16.5	20.6	26.6	26.8	26
28	2	27.6	61.1	61.1	60.4	61.2	21.4	21.5	21.4	21.8	23
29	1	9.7	57.7	57.8	55.2	56.0	34.1	34.3	36.9	37.5	33
29	2	13.2	32.1	32.4	32.0	34.8	40.3	40.5	48.9	49.1	22
30	1										
30	2										
31	1	32.2	26.1	30.4	28.5	30.1	12.3	15.4	24.4	40.9	41
31	2	36.4	36.9	38.1	35.5	35.6	8.9	9.0	15.6	16.7	36
32	1	15.7	34.3	34.3	33.1	33.6	10.7	13.3	14.0	15.0	23
32	2	20.8	41.7	41.7	38.8	39.4	14.1	14.2	15.5	15.8	26
33	1	9.5	39.9	39.9	35.2	35.7	28.4	28.5	29.6	30.1	26
33	2	9.6	37.4	38.9	34.8	35.3	32.4	32.6	34.9	35.5	27
34	1	20.2	23.2	24.0	26.6	26.7	21.1	29.3	27.5	29.3	25
34	2	20.8	23.8	23.8	28.2	28.3	29.5	36.7	21.7	30.9	30
35	1	18.3	56.4	56.4	60.9	61.0	18.6	18.7	24.2	24.6	19
35	2	21.5	72.6	75.2	74.9	75.1	20.5	28.4	30.3	32.3	25
36	1										
36	2										
37	1										
37	2										
38	1	27.1	32.4	33.5	31.8	31.9	10.1	10.2	10.9	11.1	31
38	2	37.6	44.2	44.2	44.7	45.3	5.9	7.3	4.9	7.0	32
39	1	34.3	42.4	42.4	40.5	41.1	9.0	11.2	9.0	12.8	36
39	2	19.0	62.8	65.0	59.2	59.4	15.0	15.0	18.3	18.6	27

Table B-8 – Females Standing Barefoot on a Surface Gradient of -5°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.9	59.4	59.4	59.1	60.0	45.7	45.9	49.3	50.1	16
21	2	0.9	61.3	61.3	61.4	62.4	43.5	43.7	49.0	49.8	17
22	1	11.8	51.1	52.9	59.9	60.1	20.2	20.3	21.2	21.6	7
22	2	10.9	44.7	46.3	52.4	52.6	17.3	17.3	15.8	16.0	-2
23	1	8.1	55.3	55.3	56.4	56.5	26.6	33.0	26.7	28.4	32
23	2	4.8	48.8	50.7	46.6	47.2	18.7	23.3	21.5	22.8	10
24	1	-0.6	45.3	45.3	46.6	49.1	20.9	26.0	22.4	23.9	10
24	2	2.1	54.8	54.8	54.3	54.4	26.7	33.2	27.4	27.9	15
25	1	-2.2	35.4	36.6	37.4	39.4	32.2	32.4	33.4	34.0	2
25	2	-0.8	37.0	38.3	38.8	40.9	25.6	25.7	29.1	29.6	11
26	1	2.0	24.2	24.2	22.9	23.2	34.0	42.4	36.0	36.7	15
26	2	2.8	30.1	35.0	30.3	32.0	29.8	37.1	32.0	32.6	15
27	1	-2.8	34.4	34.4	38.3	38.8	16.1	16.2	24.2	24.6	9
27	2	-1.8	34.4	34.4	40.3	40.4	17.1	17.2	28.1	28.5	11
28	1	3.6	68.3	68.3	69.3	70.4	48.8	49.0	51.3	52.3	24
28	2	4.5	67.5	67.5	70.3	70.5	45.7	45.9	49.5	50.4	25
29	1	5.2	59.8	59.8	60.4	61.2	35.1	35.3	41.1	41.8	31
29	2	7.1	50.0	50.0	50.4	51.1	25.5	25.6	29.0	29.5	13
30	1	0.5	36.4	37.8	33.5	36.4	23.7	32.9	37.3	39.8	19
30	2	4.1	22.7	26.3	22.0	23.9	23.2	23.3	31.9	32.4	23
31	1	-1.2	40.9	40.9	39.3	39.8	21.1	21.2	27.6	29.4	27
31	2	-2.9	46.8	46.8	45.2	45.3	17.0	17.1	25.2	26.8	13
32	1	9.2	59.3	61.8	57.6	62.9	25.0	25.2	28.9	29.4	28
32	2	9.7	58.8	61.3	55.2	60.3	30.4	30.6	33.5	34.1	22
33	1	3.8	42.3	42.3	42.1	42.2	35.1	43.8	33.2	33.8	25
33	2	3.6	46.7	46.7	47.1	47.7	42.6	42.8	44.8	45.7	23
34	1	0.0	48.7	56.8	48.3	51.0	26.1	32.4	29.3	29.8	14
34	2	-0.1	35.4	35.4	37.4	37.8	17.1	21.2	21.7	23.1	10
35	1	17.1	54.1	54.1	57.4	58.3	46.7	47.0	50.0	50.8	35
35	2	10.2	55.4	55.4	61.2	61.3	43.4	43.6	46.6	47.5	24
36	1	1.2	39.0	39.0	48.0	48.2	35.5	35.7	45.0	45.7	20
36	2	2.7	39.2	39.2	50.5	53.3	31.3	31.5	40.7	43.4	18
37	1	1.5	56.6	58.6	59.9	60.0	38.3	47.7	34.1	48.7	16
37	2	-0.1	63.0	65.2	67.5	67.7	31.4	39.2	30.2	30.7	11
38	1	2.8	50.5	52.2	52.7	52.8	20.3	20.4	19.1	19.4	12
38	2	1.0	49.5	51.1	51.7	51.8	23.4	29.1	21.2	21.5	12
39	1	-1.8	48.9	48.9	46.8	47.5	28.0	28.1	33.7	34.3	33
39	2	0.0	51.8	53.9	48.2	52.5	34.4	34.5	40.3	41.0	34

Table B-9 – Females Standing Barefoot on a Surface Gradient of -10°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	0.0	55.6	55.6	57.6	57.7	24.4	24.5	24.7	25.1	-12
21	2	0.0	57.2	59.1	58.4	58.6	24.4	24.5	27.6	28.0	3
22	1	11.4	58.3	60.4	65.7	65.9	24.3	24.4	27.5	27.9	20
22	2	12.1	54.4	54.4	59.0	59.1	19.3	19.4	20.9	21.3	21
23	1	4.0	53.5	53.5	53.6	54.3	18.1	18.2	19.8	20.2	-3
23	2	3.8	51.0	51.0	48.6	49.3	10.3	14.3	15.2	16.2	8
24	1	-1.8	43.2	44.6	44.7	44.8	21.9	27.2	25.0	25.4	15
24	2	1.9	43.2	43.2	41.9	42.5	44.0	44.2	44.1	44.9	22
25	1	-1.6	39.4	39.4	41.0	43.2	29.0	29.1	32.4	33.0	10
25	2	0.9	43.9	45.4	45.0	45.1	20.8	28.8	33.5	35.6	11
26	1	1.3	26.7	26.7	25.7	26.1	37.6	37.8	39.9	40.7	14
26	2	-1.4	30.0	30.0	26.1	26.4	36.4	36.5	40.7	41.4	13
27	1	-2.8	32.9	32.9	35.7	36.2	17.2	17.3	25.1	26.7	10
27	2	-3.4	32.6	32.6	37.5	38.0	9.1	10.0	27.2	37.5	8
28	1	2.7	57.2	57.2	64.1	64.3	26.1	32.6	23.1	32.9	-7
28	2	3.9	62.0	62.0	71.6	71.8	23.4	23.5	28.5	29.0	-6
29	1	7.4	57.2	57.2	59.3	59.4	31.4	31.6	36.1	36.8	29
29	2	7.2	56.4	56.4	58.9	59.7	25.4	25.5	30.8	31.3	19
30	1	1.2	45.1	45.1	42.3	42.8	27.9	28.1	36.6	39.0	18
30	2	2.2	34.9	36.2	34.1	34.6	28.8	29.0	33.6	34.1	14
31	1	-5.3	54.2	56.1	51.8	52.0	31.8	32.0	37.2	37.8	23
31	2	1.8	42.4	42.4	39.9	40.4	29.4	29.6	41.0	43.6	20
32	1	4.7	52.8	55.0	52.5	53.3	37.2	37.4	42.8	43.6	18
32	2	6.7	61.4	63.9	59.0	64.3	41.4	41.6	42.7	43.5	16
33	1	4.6	50.1	50.1	50.5	50.6	31.9	39.6	35.3	37.5	19
33	2	2.7	61.7	63.9	60.5	60.7	44.5	44.7	47.4	48.2	22
34	1	0.2	42.2	42.2	42.9	43.5	19.1	19.2	23.0	23.4	7
34	2	1.9	30.8	30.8	32.9	33.3	14.2	14.3	16.0	16.2	14
35	1	13.9	55.6	55.6	58.7	59.6	40.3	40.4	44.5	45.3	24
35	2	9.6	64.1	64.1	68.0	68.2	42.4	42.6	46.3	47.1	16
36	1	0.5	37.3	37.3	47.4	47.6	32.3	32.5	40.9	41.5	18
36	2	-0.1	38.3	38.3	47.9	48.1	34.5	34.7	46.2	47.0	20
37	1	0.5	57.4	59.5	65.5	65.7	12.1	16.7	22.1	23.6	-10
37	2	0.5	62.3	64.6	67.6	67.8	11.1	15.3	19.0	20.2	14
38	1	-2.7	48.6	50.3	50.6	50.7	28.4	28.5	27.7	28.2	14
38	2	-3.5	43.4	43.4	43.8	43.9	26.1	32.5	23.4	33.3	15
39	1	0.5	46.0	46.0	44.1	44.8	34.1	34.3	40.1	40.8	29
39	2	2.6	52.3	52.3	52.5	53.2	37.4	37.5	39.7	40.4	5

Table B-10 – Females Standing Barefoot on a Surface Gradient of -15°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	-0.9	56.8	56.8	56.0	56.8	18.3	25.4	22.0	23.4	22
21	2	1.9	61.1	61.1	61.1	62.0	23.1	23.2	26.9	27.4	81
22	1	8.8	48.4	50.2	56.0	56.2	26.2	26.3	24.3	24.7	4
22	2	7.5	51.9	53.7	59.7	59.9	18.0	18.1	19.3	19.7	-1
23	1	3.7	46.7	46.7	47.2	47.9	16.0	16.0	20.2	20.6	17
23	2	6.9	52.5	52.5	51.2	51.9	17.0	17.1	21.3	22.6	22
24	1	-2.5	42.8	42.8	44.7	44.8	23.0	28.5	21.0	29.8	18
24	2	0.6	47.0	47.0	46.8	47.4	24.2	24.3	26.8	27.2	25
25	1	-1.7	36.8	42.9	39.0	41.2	27.8	27.9	30.3	30.8	4
25	2	0.5	42.2	43.7	43.4	45.7	27.4	27.6	30.6	31.1	15
26	1	0.2	29.4	29.4	26.7	27.0	37.7	47.0	39.7	40.4	9
26	2	3.0	33.9	33.9	31.0	31.4	31.4	39.1	35.0	35.6	10
27	1	-2.5	33.9	33.9	33.1	33.6	21.3	21.4	24.2	24.6	16
27	2	-1.1	36.9	36.9	42.5	42.6	14.1	14.2	26.0	27.8	10
28	1	2.4	60.4	60.4	68.6	68.8	31.4	31.6	40.3	41.0	18
28	2	4.6	67.7	67.7	71.4	71.5	45.8	45.9	48.6	49.5	24
29	1	8.9	54.9	54.9	59.0	59.9	23.2	23.3	25.8	26.2	4
29	2	5.5	56.5	56.5	57.9	58.7	14.7	16.0	13.3	13.3	-4
30	1	0.8	35.9	37.3	33.8	36.7	24.9	25.0	34.9	37.2	14
30	2	-1.4	46.2	46.2	43.4	44.0	27.9	28.0	37.8	40.3	15
31	1	-2.7	55.0	55.0	52.9	53.6	29.9	30.0	33.6	34.2	7
31	2	-1.9	53.2	53.2	51.2	51.9	17.5	24.3	27.4	29.1	11
32	1	5.4	55.1	57.4	53.6	54.5	45.3	45.5	45.9	46.7	32
32	2	5.7	61.7	61.7	60.6	61.5	39.6	39.7	42.5	43.3	21
33	1	4.6	44.2	44.2	46.1	46.3	30.3	30.5	31.5	32.1	27
33	2	5.9	42.7	42.7	42.8	43.4	35.2	35.4	37.6	38.3	19
34	1	1.7	29.4	29.4	33.2	33.6	20.3	20.4	27.7	29.4	12
34	2	1.2	32.4	32.4	33.1	33.5	22.9	23.0	27.7	28.2	15
35	1	11.5	54.1	54.1	61.6	61.8	40.2	40.4	43.5	44.3	15
35	2	12.8	66.8	66.8	70.0	70.1	42.4	42.6	50.8	51.7	29
36	1	3.9	36.1	36.1	45.3	45.4	37.4	37.6	45.3	46.0	22
36	2	1.1	38.2	38.2	47.9	48.1	35.5	35.6	44.6	45.3	18
37	1	0.2	54.7	56.6	60.6	60.8	29.6	29.7	34.9	35.5	12
37	2	0.7	59.5	61.5	62.4	62.5	37.2	46.3	40.3	41.1	10
38	1	-2.3	40.6	47.2	46.2	48.6	5.9	7.3	4.6	6.5	-17
38	2	-8.0	39.9	39.9	41.5	42.0	14.9	18.5	14.4	14.7	-7
39	1	3.0	53.4	53.4	51.4	52.1	40.5	40.7	45.4	46.2	35
39	2	1.5	50.9	50.9	48.7	49.4	41.2	41.4	46.4	47.2	40

Table B-11 – Females Standing Barefoot on a Surface Gradient of -20°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	5.0	61.5	61.5	61.2	62.1	49.4	49.6	53.5	54.5	39
21	2	3.0	60.9	60.9	60.4	61.3	36.4	36.6	40.1	40.8	27
22	1	8.7	43.5	45.0	51.9	52.1	17.1	17.2	16.2	16.5	-16
22	2	8.9	54.9	56.8	62.5	62.7	11.7	11.7	12.2	12.4	18
23	1	5.7	56.7	56.7	56.7	57.4	24.2	24.3	29.3	31.2	24
23	2	5.4	58.8	58.8	56.8	57.6	25.4	25.5	28.2	28.7	25
24	1	-0.6	39.4	39.4	41.8	44.0	29.0	36.1	28.0	39.9	13
24	2	-4.2	50.5	52.2	54.5	54.7	60.4	74.9	51.7	73.7	12
25	1	0.3	35.8	37.0	39.3	41.4	41.5	51.8	36.9	52.8	5
25	2	0.2	41.3	42.7	43.6	43.7	36.6	40.1	38.6	38.7	17
26	1	3.4	42.0	43.7	39.7	43.2	29.8	37.1	29.1	29.6	6
26	2	0.8	46.8	46.8	42.2	42.7	27.3	27.4	31.1	31.6	7
27	1	-4.4	30.0	30.0	35.0	35.4	17.2	17.3	28.3	30.2	9
27	2	-1.5	42.6	42.6	46.8	47.5	15.1	15.2	27.0	28.8	8
28	1	2.4	65.2	65.2	68.9	69.1	45.8	57.2	43.4	62.1	21
28	2	3.8	66.6	66.6	68.9	69.0	45.8	46.0	48.3	49.2	22
29	1	2.9	53.0	53.0	56.5	57.3	23.3	23.4	27.8	28.3	-2
29	2	4.6	55.7	55.7	56.1	56.9	34.0	42.3	38.8	41.2	17
30	1	-2.8	44.9	44.9	43.2	43.8	33.1	33.2	36.8	37.4	8
30	2	-0.9	26.7	27.7	25.9	28.1	36.7	36.9	39.8	40.5	14
31	1	-9.8	64.9	64.9	60.7	61.6	14.9	18.4	15.7	16.7	-12
31	2	-4.0	55.2	55.2	52.5	53.2	17.6	21.9	22.9	24.4	9
32	1	5.1	52.3	54.5	49.9	54.3	40.1	40.3	40.8	41.6	19
32	2	10.8	65.7	65.7	65.9	66.9	33.2	33.3	34.5	35.2	20
33	1	3.7	47.2	47.2	48.8	49.4	33.1	41.1	36.7	39.0	21
33	2	6.3	44.3	44.3	45.2	45.4	30.7	38.2	34.5	36.6	19
34	1	-3.3	56.3	56.3	56.6	56.7	13.9	17.3	16.9	18.0	7
34	2	0.3	39.7	39.7	43.1	43.3	20.1	20.2	25.7	27.4	7
35	1	11.1	64.9	64.9	68.8	69.7	35.1	48.6	49.4	52.6	20
35	2	10.7	65.2	65.2	69.9	70.1	35.6	44.2	46.7	49.6	21
36	1	1.9	34.8	34.8	43.6	43.8	35.3	35.5	42.2	42.9	18
36	2	-0.1	37.2	37.2	45.7	45.8	38.4	38.5	46.2	47.0	18
37	1	2.1	62.2	64.5	68.2	68.5	30.9	38.4	37.2	37.9	13
37	2	1.8	66.6	68.8	69.5	69.6	38.3	47.7	42.0	42.8	11
38	1	-5.5	44.0	45.4	46.1	46.2	28.8	35.8	24.5	34.9	9
38	2	-9.6	40.9	42.2	43.6	43.7	29.3	36.5	25.5	36.4	2
39	1	1.0	45.3	45.3	45.1	45.7	36.0	36.1	39.4	40.0	18
39	2	3.0	53.6	53.6	54.1	54.9	29.3	29.4	32.7	33.3	16

Table B-12 – Females Standing Barefoot on a Surface Gradient of -25°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	5.4	56.7	56.8	55.4	56.2	28.0	34.8	35.4	37.6	44
21	2	2.2	59.2	59.2	59.4	60.2	38.0	38.2	42.0	42.7	37
22	1	9.8	55.8	57.8	61.9	62.1	20.2	20.3	21.5	21.9	14
22	2	10.2	52.4	54.3	61.0	61.2	17.1	17.2	17.5	17.8	3
23	1	7.9	65.3	65.4	66.9	67.0	17.0	17.1	20.0	20.3	16
23	2	8.6	68.4	68.4	69.0	69.1	22.0	22.1	25.6	26.0	27
24	1	-4.6	48.1	49.8	50.1	52.8	35.1	43.7	32.3	46.1	22
24	2	-1.8	53.6	53.6	52.7	52.9	39.2	39.4	44.1	44.9	28
25	1	-0.5	48.2	56.1	52.6	55.5	21.5	21.6	23.8	24.2	10
25	2	-0.3	46.3	53.9	51.2	53.9	29.7	29.8	31.8	32.4	6
26	1	0.6	27.7	28.6	26.8	26.9	36.4	36.6	38.2	38.9	7
26	2	0.3	33.6	34.8	32.0	32.1	35.1	43.8	32.8	33.5	9
27	1	-3.4	26.4	26.4	29.9	30.3	19.2	19.3	26.0	26.4	9
27	2	-1.6	36.5	37.9	39.9	40.0	10.0	10.1	21.7	36.3	8
28	1	4.5	67.1	67.1	70.9	71.1	43.7	43.9	47.5	48.4	19
28	2	1.8	64.7	64.7	65.0	65.1	46.5	46.7	50.7	51.6	26
29	1	5.7	57.0	57.1	59.8	60.7	23.3	23.4	26.8	27.3	3
29	2	5.5	53.3	55.3	53.6	54.3	27.6	34.4	32.3	34.3	25
30	1	0.4	39.9	41.4	38.9	39.4	23.8	23.9	33.6	35.8	10
30	2	-1.2	50.5	50.5	46.8	47.5	24.2	33.6	35.2	37.5	10
31	1	-4.3	59.9	62.2	53.6	58.1	31.1	38.7	29.7	42.3	21
31	2	-6.2	58.9	58.9	53.3	54.0	28.2	35.1	26.1	37.2	31
32	1	7.5	62.1	62.1	62.4	63.4	21.3	26.5	29.0	30.9	13
32	2	9.1	54.3	54.3	55.2	56.1	39.4	49.1	39.7	40.5	18
33	1	3.0	45.5	47.1	45.0	45.1	23.2	23.3	23.2	23.6	24
33	2	6.3	42.0	42.0	42.4	42.9	39.3	39.4	41.0	41.7	18
34	1	2.0	42.0	42.0	43.8	43.9	27.8	27.9	29.1	29.5	14
34	2	1.3	43.7	43.7	45.1	47.5	18.3	20.0	16.8	21.3	2
35	1	10.7	61.3	61.3	67.1	67.2	35.2	35.4	45.7	48.7	20
35	2	9.2	70.9	70.9	75.9	76.1	42.4	42.6	48.8	49.7	19
36	1	2.4	33.8	33.8	43.3	43.5	34.5	34.6	42.6	43.4	19
36	2	1.5	42.1	42.1	52.6	52.8	37.5	37.7	48.2	49.0	18
37	1	0.9	55.2	57.2	64.8	68.4	19.2	19.3	27.5	29.3	-4
37	2	1.4	65.1	67.4	68.6	68.9	25.1	25.2	30.9	31.4	33
38	1	-4.9	43.3	44.7	45.4	45.5	11.9	13.0	9.5	12.0	10
38	2	-5.3	39.7	39.7	41.6	42.1	29.8	37.1	26.2	37.3	10
39	1	4.9	47.2	49.1	44.7	45.4	28.3	28.5	37.5	39.9	46
39	2	4.1	48.8	50.8	46.6	50.7	35.7	35.9	44.2	47.0	52

Table B-13 – Females Standing Barefoot on a Surface Gradient of -30°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.0	60.4	60.4	61.5	62.4	49.2	49.4	55.0	55.9	30
21	2	-0.1	57.7	57.7	57.5	58.4	36.6	36.8	40.2	41.0	19
22	1	13.3	53.6	53.6	59.5	59.7	23.4	29.2	23.8	24.2	13
22	2	11.0	57.3	59.3	64.7	64.9	19.2	19.3	20.6	20.9	11
23	1	6.5	49.1	49.1	49.1	49.8	18.0	18.1	20.1	20.4	10
23	2	4.7	55.9	57.9	54.7	54.9	11.2	14.0	10.8	15.4	7
24	1	-0.7	48.6	48.6	49.1	49.2	43.1	53.9	40.6	58.2	26
24	2	-1.7	52.5	52.5	50.8	50.9	55.0	55.3	56.6	57.6	22
25	1	3.1	48.4	48.6	48.6	50.2	28.1	29.8	30.2	33.1	16
25	2	1.7	51.2	52.1	53.1	53.9	32.4	34.7	36.5	37.8	13
26	1	-2.0	24.8	25.6	23.4	23.4	39.4	39.5	42.7	43.4	6
26	2	-1.7	46.8	48.6	41.0	41.2	36.5	36.7	39.2	39.9	8
27	1	-2.6	37.2	37.2	34.7	35.2	22.3	22.3	27.1	27.5	19
27	2	-1.2	30.5	30.5	35.9	36.0	11.1	11.2	26.2	43.9	8
28	1	1.7	65.4	65.4	67.7	67.9	31.2	38.8	28.7	41.0	18
28	2	3.4	63.6	63.7	65.9	66.9	52.9	53.1	55.6	56.6	9
29	1	5.2	59.0	59.0	59.7	60.6	13.8	19.1	23.4	25.0	18
29	2	6.6	56.8	56.8	56.5	57.3	45.4	45.6	50.2	51.1	8
30	1	1.7	40.4	40.4	40.3	40.9	27.0	27.1	37.5	40.0	13
30	2	-1.3	40.2	40.2	37.8	38.3	35.7	35.8	39.3	40.0	15
31	1	-7.4	52.3	54.0	51.1	51.2	22.9	25.0	25.3	25.3	-11
31	2	-6.6	62.2	62.2	57.5	58.2	21.0	21.1	26.8	27.2	14
32	1	5.4	52.7	54.9	51.0	55.6	42.7	42.9	46.5	47.4	23
32	2	6.5	53.8	56.0	51.1	55.6	48.0	48.2	49.0	49.8	23
33	1	5.7	41.7	41.7	43.3	43.9	28.2	35.1	30.3	30.9	22
33	2	6.9	53.2	53.2	53.7	53.9	34.1	42.5	33.2	33.8	18
34	1	1.6	35.3	35.3	36.8	37.3	15.1	15.2	16.2	16.5	12
34	2	3.0	35.3	35.3	36.3	36.8	16.4	20.4	24.3	25.9	16
35	1	11.9	60.8	60.8	62.7	63.6	19.8	24.6	22.5	23.9	13
35	2	8.6	64.5	64.5	66.6	66.8	38.6	38.8	42.9	43.6	16
36	1	2.1	37.2	37.2	45.5	45.6	34.3	34.5	39.6	40.3	15
36	2	2.2	38.2	38.2	48.4	48.5	34.4	34.5	41.9	42.6	19
37	1	2.8	66.4	68.8	72.3	72.5	23.2	23.3	25.5	25.9	-4
37	2	5.4	64.0	66.4	70.1	74.1	20.3	20.4	22.3	22.6	-5
38	1	-3.3	41.9	43.3	44.0	44.1	11.9	13.0	10.0	12.7	11
38	2	-7.2	38.8	38.8	39.8	40.4	26.6	33.1	23.1	32.9	8
39	1	2.0	46.4	48.3	44.5	48.5	38.5	38.6	43.7	44.5	34
39	2	1.9	48.0	49.8	44.5	48.3	33.6	33.7	37.2	37.9	33

Table C-1 – Females Standing in Small Heeled Shoes on a Surface Gradient of 0°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.8	55.2	55.2	55.4	56.2	27.5	27.6	31.6	32.1	28
21	2	3.3	57.0	57.0	56.9	57.7	24.4	24.5	26.6	27.1	15
22	1	13.9	57.7	57.7	63.9	64.1	35.1	43.7	37.4	38.1	37
22	2	12.9	56.0	56.0	60.9	61.1	27.3	27.4	30.5	31.0	27
23	1	8.2	61.1	61.1	60.6	61.4	28.8	35.9	28.5	29.0	26
23	2	4.4	72.3	74.8	69.4	69.6	24.2	24.3	26.1	26.5	15
24	1	3.9	40.8	47.4	41.9	44.2	28.5	28.6	34.3	36.5	21
24	2	-0.1	39.8	41.2	39.9	40.0	31.4	39.1	33.7	34.3	22
25	1	0.4	28.1	29.0	29.7	31.3	30.6	30.7	33.7	34.3	15
25	2	1.2	36.7	36.7	35.5	36.0	19.0	19.1	20.4	20.8	14
26	1	0.2	39.6	39.6	34.0	34.4	36.1	36.2	39.1	39.8	14
26	2	4.3	20.9	21.7	18.8	20.4	22.3	22.4	25.2	25.7	15
27	1	3.0	40.5	40.5	40.6	41.2	23.3	32.4	18.5	19.7	1
27	2	-1.8	33.3	33.3	35.4	35.8	13.1	13.2	20.2	21.5	9
28	1	4.1	65.4	65.4	73.9	74.1	33.2	33.3	38.5	39.2	25
28	2	3.4	67.8	67.8	70.3	71.4	49.0	49.1	52.0	53.0	23
29	1	4.5	61.8	61.8	61.9	62.8	32.2	32.3	38.2	38.8	43
29	2	4.1	55.2	55.2	55.3	56.0	35.3	35.5	40.3	41.0	31
30	1	3.5	25.9	26.9	23.8	25.8	23.4	32.4	36.9	39.3	25
30	2	2.2	29.5	29.5	29.4	29.8	36.2	36.3	40.2	40.9	23
31	1	-2.8	50.4	52.3	44.7	48.4	29.3	29.5	39.4	41.9	18
31	2	0.5	41.3	42.7	40.0	40.1	28.5	28.6	33.2	33.8	17
32	1	12.0	58.5	58.5	58.5	58.5	39.2	39.9	39.2	39.9	55
32	2	6.5	37.4	38.9	35.9	39.0	26.3	26.4	27.9	28.4	19
33	1	5.3	37.2	37.2	36.0	36.5	32.5	32.7	34.3	34.9	20
33	2	5.0	52.7	54.5	47.7	47.8	22.9	28.5	21.8	22.2	20
34	1	0.8	37.1	37.1	37.8	38.3	33.9	34.0	36.3	37.0	11
34	2	0.8	38.5	38.5	40.7	41.2	21.1	21.2	26.3	26.7	7
35	1	12.0	61.4	61.4	62.7	63.6	41.5	41.6	45.7	46.5	23
35	2	10.2	61.4	61.4	62.6	63.5	45.1	45.3	47.1	47.9	36
36	1	2.1	41.9	43.3	50.7	50.8	30.4	30.6	41.6	44.4	22
36	2	1.1	33.2	33.2	40.7	40.8	36.3	36.5	39.0	39.7	12
37	1	6.5	47.0	47.0	53.6	53.7	22.0	22.0	26.1	26.6	11
37	2	3.7	46.4	46.4	52.3	52.4	21.2	21.3	23.2	23.6	2
38	1	-6.7	47.7	49.3	49.0	49.2	24.3	24.5	24.3	24.8	14
38	2	-5.3	46.1	47.6	48.3	48.4	10.1	11.0	11.2	11.2	12
39	1	2.8	36.2	37.7	33.0	35.9	24.7	24.8	27.8	28.3	39
39	2	3.5	43.1	44.8	40.2	43.7	64.2	64.5	67.5	68.7	39

Table C-2 – Females Standing in Small Heeled Shoes on a Surface Gradient of 5°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.5	61.2	61.3	60.7	61.5	28.5	28.7	32.6	33.2	17
21	2	1.6	59.5	59.5	61.6	61.8	28.2	35.1	26.2	26.6	4
22	1	12.8	53.4	53.4	56.1	56.9	22.2	22.3	26.1	26.5	21
22	2	10.2	48.2	48.2	54.6	54.7	20.2	20.3	21.2	21.6	7
23	1	5.2	52.3	52.3	51.5	52.2	26.5	32.9	30.8	32.7	27
23	2	10.7	56.6	56.6	56.5	57.4	27.4	27.5	31.8	32.4	38
24	1	2.4	42.4	42.4	45.4	45.6	22.4	22.5	28.5	30.3	13
24	2	2.2	47.4	47.4	48.5	48.6	23.0	28.6	24.1	25.7	9
25	1	0.0	38.8	40.2	39.5	39.6	22.7	31.5	33.2	35.4	7
25	2	0.1	41.4	41.4	40.8	41.4	16.9	23.3	26.5	28.2	7
26	1	2.5	30.4	31.5	29.3	29.7	37.9	47.2	38.1	38.8	10
26	2	1.6	36.2	36.2	34.0	34.5	29.8	37.2	29.8	30.3	17
27	1	-1.7	34.1	34.1	33.6	34.0	17.2	17.3	19.9	20.2	8
27	2	-0.2	34.4	34.4	37.8	38.4	17.1	17.2	23.6	24.0	9
28	1	0.7	64.8	64.8	70.2	70.4	22.0	27.3	22.6	32.2	13
28	2	4.2	67.2	69.9	68.6	69.7	44.8	45.0	49.9	50.8	20
29	1	5.8	58.6	58.6	57.1	58.0	35.1	43.6	34.0	48.5	15
29	2	5.5	56.2	56.2	57.3	58.1	29.5	29.6	34.8	35.4	33
30	1	-1.2	36.2	37.5	34.9	35.3	22.8	31.6	36.1	38.4	16
30	2	0.4	31.1	36.0	32.9	33.4	34.8	34.9	39.4	40.1	16
31	1	-6.4	68.4	70.7	67.2	67.4	24.4	24.5	28.9	29.4	-16
31	2	-3.2	62.8	62.8	58.7	59.5	34.0	34.1	39.0	39.6	24
32	1	5.6	54.9	54.9	53.2	54.0	21.8	27.2	22.1	22.5	12
32	2	5.2	57.9	57.9	61.4	62.3	31.5	39.3	32.0	45.6	17
33	1	7.5	45.8	47.6	45.1	45.7	55.0	55.3	57.8	58.8	34
33	2	4.2	49.0	49.0	47.8	47.9	41.5	41.7	43.5	44.3	19
34	1	-1.4	34.1	34.1	35.0	35.5	24.1	24.2	26.3	26.8	11
34	2	-4.6	46.1	46.1	49.8	49.9	11.0	15.3	16.2	17.2	3
35	1	14.7	71.1	71.1	75.3	75.5	28.2	28.3	39.5	42.1	20
35	2	8.4	48.8	48.8	58.5	58.6	34.3	34.4	39.9	40.6	12
36	1	0.5	39.4	39.4	48.1	48.3	34.5	34.6	44.2	45.0	17
36	2	-0.1	39.0	39.0	48.3	48.4	33.5	33.7	43.3	44.0	14
37	1	2.3	51.6	53.5	56.3	59.5	23.1	23.2	26.3	26.7	21
37	2	1.2	51.2	52.9	55.8	55.9	21.3	21.4	24.2	24.6	21
38	1	-9.9	43.7	45.2	45.0	45.1	17.2	17.3	18.0	18.3	14
38	2	-10.2	46.0	47.5	47.9	48.1	30.4	30.6	31.6	32.2	14
39	1	2.7	44.5	46.3	42.3	46.0	33.6	33.7	39.2	39.9	17
39	2	1.3	41.9	41.9	40.9	41.5	46.3	46.5	49.9	50.7	35

Table C-3 – Females Standing in Small Heeled Shoes on a Surface Gradient of 10°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	1.3	58.7	58.7	58.7	59.6	26.3	26.4	28.8	29.3	0
21	2	-0.2	56.4	56.4	56.4	57.2	28.4	28.5	30.8	31.4	4
22	1	9.6	53.5	55.4	59.7	59.9	20.0	20.0	21.0	21.3	6
22	2	14.9	50.3	50.3	53.8	54.0	15.1	15.1	16.3	17.3	29
23	1	7.3	59.1	59.1	60.2	60.3	33.6	41.9	32.8	33.4	32
23	2	9.9	60.6	60.6	59.2	60.1	20.4	20.4	23.3	23.7	17
24	1	3.5	43.7	43.7	44.5	45.1	21.3	29.5	33.2	35.4	16
24	2	3.6	39.0	39.0	39.3	39.9	25.3	25.4	30.4	30.9	20
25	1	1.5	44.8	46.4	45.4	45.6	22.6	28.1	30.4	32.4	16
25	2	-2.5	46.0	47.6	46.5	46.6	28.4	28.6	30.9	31.5	3
26	1	1.6	37.3	38.5	36.0	36.1	30.4	37.9	31.4	32.0	29
26	2	1.2	25.1	25.1	23.7	24.0	41.2	51.4	38.3	54.8	8
27	1	-3.4	26.7	26.7	29.5	29.9	20.2	20.2	24.7	25.1	10
27	2	1.5	42.9	44.7	46.2	46.9	14.1	14.2	20.4	20.7	8
28	1	2.6	66.2	66.2	73.9	74.1	23.4	23.5	34.6	36.8	16
28	2	6.9	73.4	73.4	73.8	74.0	45.2	45.4	50.7	51.6	10
29	1	3.9	59.0	59.1	61.4	62.3	24.1	24.2	28.6	29.1	4
29	2	6.9	55.3	57.5	54.9	55.8	41.3	41.5	45.5	46.3	15
30	1	-0.2	38.1	38.1	38.1	38.6	37.0	37.2	44.2	44.9	22
30	2	4.5	24.5	28.4	23.2	28.7	21.9	30.4	32.2	34.3	22
31	1	-6.3	62.8	65.0	64.0	64.2	29.9	37.2	33.1	35.2	-13
31	2	-3.5	62.6	64.7	60.9	61.1	32.0	32.1	38.3	38.9	19
32	1	5.1	48.5	50.5	47.2	47.9	34.6	43.1	32.5	33.1	21
32	2	8.5	53.3	53.3	52.6	53.4	23.0	31.8	29.9	31.8	21
33	1	4.4	42.8	42.8	39.4	40.0	13.5	16.8	12.3	17.6	19
33	2	5.8	48.2	48.2	47.1	47.7	25.4	25.5	25.6	26.1	17
34	1	-2.3	53.2	55.0	53.8	53.9	22.2	22.3	27.1	28.8	9
34	2	-1.2	33.0	33.0	34.3	34.4	18.3	18.3	19.9	20.3	4
35	1	7.9	50.2	50.2	57.0	57.2	36.6	36.8	40.2	41.0	19
35	2	11.0	61.9	61.9	64.4	64.6	26.3	26.5	29.2	29.7	14
36	1	0.5	40.7	42.0	49.4	49.5	39.4	39.6	47.2	48.0	19
36	2	-0.7	37.0	37.0	46.5	46.7	34.2	34.3	39.5	40.1	9
37	1	-0.6	52.2	54.0	56.9	57.1	27.2	27.3	31.3	31.8	25
37	2	-0.9	51.9	53.6	55.2	55.4	21.2	21.2	23.1	23.5	25
38	1	-3.7	47.7	49.3	49.3	49.4	24.5	30.4	24.4	24.9	13
38	2	-8.8	43.9	45.4	47.0	47.1	25.4	25.5	26.0	26.5	11
39	1	2.4	50.5	50.5	49.4	50.2	37.2	37.4	39.6	40.3	34
39	2	1.9	47.9	49.9	44.8	48.8	49.8	50.1	52.7	53.6	16

Table C-4 – Females Standing in Small Heeled Shoes on a Surface Gradient of 15°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.3	61.0	61.0	61.4	62.3	39.8	39.9	42.4	43.1	24
21	2	0.3	60.8	60.8	62.1	63.0	32.5	32.6	37.5	38.1	22
22	1	11.8	47.5	49.1	53.1	53.3	20.3	20.4	20.7	21.1	11
22	2	11.9	57.2	59.1	62.9	63.0	24.4	24.5	27.6	28.0	24
23	1	6.6	52.6	54.4	63.1	63.3	5.5	6.0	23.3	32.1	-17
23	2	7.3	58.2	58.2	55.6	56.3	28.3	35.2	25.2	35.9	24
24	1	-0.1	43.7	43.8	42.5	42.6	45.1	45.3	45.5	46.3	22
24	2	-0.4	47.7	47.7	48.2	48.3	37.9	47.2	35.9	51.2	18
25	1	-0.9	44.3	45.9	46.8	46.9	25.4	25.5	28.9	29.4	6
25	2	-2.3	45.8	45.8	46.6	46.8	24.0	24.1	25.6	26.1	14
26	1	3.8	27.3	27.3	27.3	27.3	25.0	25.4	25.0	25.4	15
26	2	4.0	37.1	38.7	34.8	38.1	35.1	43.8	36.4	37.1	13
27	1	-2.4	31.9	33.1	35.0	35.1	16.2	16.3	22.1	22.4	9
27	2	-1.3	34.7	34.7	37.9	38.4	16.1	16.2	23.4	24.9	10
28	1	6.7	72.7	72.7	76.0	76.3	43.6	43.8	48.8	49.6	24
28	2	4.1	67.9	67.9	72.7	72.9	47.5	47.7	53.2	54.2	21
29	1	5.3	56.6	56.6	56.7	57.5	45.3	45.5	50.2	51.0	31
29	2	5.2	60.3	60.3	60.2	61.1	44.3	44.5	48.5	49.3	16
30	1	1.9	30.6	30.6	29.1	29.5	37.7	37.8	40.4	41.1	20
30	2	3.4	25.1	29.1	23.7	24.0	26.0	36.1	37.6	40.0	22
31	1	-4.0	47.7	49.5	45.5	49.3	24.0	24.1	30.8	31.3	19
31	2	-1.0	55.0	55.0	52.7	53.4	22.0	22.0	26.8	27.2	16
32	1	3.0	54.9	54.9	56.0	56.9	17.1	21.3	17.4	24.8	13
32	2	3.5	53.5	55.6	50.9	51.7	27.2	33.8	26.4	37.7	13
33	1	5.1	42.0	42.0	41.9	42.5	39.6	39.8	42.2	43.0	19
33	2	5.2	45.1	46.7	44.2	44.4	39.6	39.8	40.0	40.8	17
34	1	-1.8	35.6	35.6	38.1	38.2	22.2	22.3	25.4	25.9	7
34	2	-1.1	29.6	29.6	33.1	33.6	14.1	14.2	17.8	18.1	3
35	1	12.3	52.3	52.3	55.7	56.5	35.5	35.6	45.6	48.5	19
35	2	12.2	65.5	65.5	67.2	68.2	21.6	26.8	30.7	32.6	19
36	1	0.4	43.5	45.0	49.9	50.1	39.5	39.7	47.0	47.8	19
36	2	1.6	38.7	38.7	47.5	47.6	37.4	37.6	45.3	46.0	16
37	1	1.4	32.0	33.1	41.0	43.2	16.2	16.3	17.3	17.6	-18
37	2	2.7	42.1	43.6	48.1	48.3	23.1	23.2	26.3	26.8	56
38	1	-5.9	46.8	48.4	49.3	49.4	24.3	24.5	23.7	24.1	13
38	2	-10.1	43.9	45.4	46.6	46.7	25.2	25.3	25.8	26.3	12
39	1	0.6	40.9	42.5	38.5	41.8	31.5	39.2	35.9	38.2	16
39	2	3.1	43.0	44.7	39.5	42.9	43.5	43.6	48.3	49.1	22

Table C-5 – Females Standing in Small Heeled Shoes on a Surface Gradient of 20°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	3.7	65.3	65.3	65.6	66.6	45.8	57.1	44.5	45.4	29
21	2	1.8	68.2	68.2	68.3	69.3	43.6	54.3	44.4	45.2	32
22	1	11.8	48.7	50.3	56.9	57.1	16.6	20.7	15.1	21.5	4
22	2	10.8	56.4	58.3	62.6	62.8	17.1	17.2	20.1	20.4	23
23	1	7.7	58.5	58.5	58.3	58.4	20.1	20.2	22.7	23.1	30
23	2	7.9	51.3	51.3	49.8	50.5	36.7	45.8	37.4	38.1	34
24	1	3.0	41.5	41.5	42.4	42.5	21.3	21.4	26.1	26.6	19
24	2	5.8	46.6	46.6	46.5	47.1	18.4	22.9	27.1	28.8	21
25	1	1.7	52.1	53.9	52.4	52.6	23.1	32.0	33.7	35.9	11
25	2	0.2	43.6	45.1	47.5	47.6	32.2	32.3	35.0	35.6	2
26	1	2.3	32.9	32.9	28.9	29.3	36.0	36.1	40.0	40.7	12
26	2	4.4	24.0	24.8	20.7	20.8	36.3	36.4	39.6	40.3	14
27	1	-1.9	36.2	36.2	35.0	35.5	25.4	25.5	29.2	29.7	15
27	2	-2.0	36.0	36.0	35.1	35.5	22.3	22.4	25.9	26.3	18
28	1	3.6	64.0	64.1	69.4	69.6	47.8	48.0	52.8	53.8	15
28	2	3.4	64.8	64.9	68.8	68.9	48.8	49.0	54.8	55.8	18
29	1	2.5	57.7	57.7	57.4	58.3	41.7	41.9	46.5	47.4	15
29	2	5.6	59.2	59.2	58.7	59.5	39.6	39.8	45.4	46.3	17
30	1	2.7	48.9	57.1	43.2	45.7	26.8	37.3	40.5	43.1	25
30	2	5.4	34.1	39.6	32.6	35.4	36.8	37.0	42.1	42.8	23
31	1	-2.3	46.3	47.9	46.9	47.0	30.4	30.5	34.5	35.1	-7
31	2	-5.9	49.7	51.5	49.4	49.5	54.7	68.5	48.5	69.8	-12
32	1	7.3	46.7	48.6	44.2	48.0	23.3	23.4	24.6	25.0	16
32	2	3.8	70.9	73.7	69.0	70.1	31.1	38.7	30.3	43.3	7
33	1	7.8	37.5	37.5	36.9	37.4	32.4	32.6	35.2	35.8	25
33	2	8.3	35.7	41.4	34.2	37.2	31.0	31.2	34.1	34.7	20
34	1	-2.9	36.4	36.4	43.2	43.3	14.1	14.2	19.3	19.7	-1
34	2	-3.7	36.6	36.6	39.0	39.5	31.0	34.0	24.1	30.7	14
35	1	11.0	66.1	66.1	69.0	69.2	52.1	52.4	56.9	57.9	22
35	2	7.0	61.5	61.5	63.9	64.8	46.5	46.7	50.0	50.9	19
36	1	2.3	39.0	39.0	46.6	46.7	37.6	37.8	45.1	45.9	19
36	2	2.5	39.1	39.1	47.8	48.0	32.4	32.6	41.6	42.3	22
37	1	1.8	55.1	57.0	59.9	60.1	14.7	16.0	17.2	17.2	36
37	2	4.1	49.1	50.8	52.7	52.9	22.1	22.2	24.7	25.1	43
38	1	-2.9	44.1	45.6	47.2	47.3	12.8	15.9	10.9	15.5	-5
38	2	-5.9	46.3	47.8	48.9	49.0	25.4	25.5	26.0	26.5	15
39	1	2.7	50.2	52.4	48.3	52.7	23.0	23.1	26.8	27.3	58
39	2	1.5	47.9	49.9	45.2	49.2	33.4	41.5	37.6	40.0	34

Table C-6 – Females Standing in Small Heeled Shoes on a Surface Gradient of 25°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.4	57.4	57.4	57.6	58.4	47.6	47.8	52.7	53.7	36
21	2	2.2	60.4	60.4	59.4	60.3	37.3	37.5	42.6	43.3	51
22	1	9.6	45.8	45.8	52.5	52.7	21.2	21.3	21.3	21.6	7
22	2	10.5	54.4	56.2	58.9	59.0	21.1	21.2	21.7	22.1	8
23	1	6.3	48.3	48.3	46.4	47.0	24.0	29.8	24.4	24.8	24
23	2	5.3	49.7	51.4	58.7	58.9	18.2	22.7	26.5	28.2	-19
24	1	3.5	38.9	38.9	37.6	38.2	34.0	34.2	38.7	39.4	28
24	2	1.7	44.7	44.7	43.6	44.2	24.4	30.3	31.3	33.2	28
25	1	1.0	47.2	48.8	47.7	47.8	35.9	36.1	37.4	38.0	10
25	2	1.5	39.6	40.9	39.8	39.9	24.6	34.1	34.8	37.1	15
26	1	0.9	21.6	22.3	21.0	21.0	35.7	44.6	35.4	50.6	21
26	2	4.3	25.5	25.5	22.0	23.9	35.3	35.5	39.3	40.0	15
27	1	-2.4	35.4	35.4	39.6	40.1	17.1	17.2	25.0	26.6	8
27	2	-3.3	37.1	38.5	42.8	42.9	16.2	16.3	26.8	28.6	11
28	1	2.9	60.5	60.5	64.8	65.7	45.6	45.8	51.4	52.3	15
28	2	3.1	70.4	70.4	71.8	71.9	46.9	47.0	50.6	51.6	3
29	1	3.7	55.5	55.5	57.4	57.6	23.2	23.3	25.2	25.6	-8
29	2	4.5	57.7	57.7	60.5	61.4	11.2	11.3	20.4	34.0	9
30	1	4.4	50.5	50.5	45.6	46.2	17.3	17.4	26.5	26.9	24
30	2	6.4	36.7	38.2	34.9	37.9	35.9	36.1	39.3	40.0	19
31	1	-5.7	37.3	37.3	35.1	35.6	32.5	32.6	36.8	37.5	19
31	2	-0.1	48.1	49.8	43.9	47.5	30.0	37.2	39.2	41.7	28
32	1	3.8	58.8	58.8	59.0	59.9	16.1	16.2	23.1	24.6	16
32	2	-0.3	63.5	63.5	65.5	66.4	22.5	28.0	14.6	24.2	16
33	1	4.6	44.5	44.5	44.1	44.8	31.9	39.8	33.7	34.3	22
33	2	6.1	47.8	49.5	46.6	46.7	40.9	50.9	37.2	53.1	20
34	1	-4.0	37.6	38.9	38.4	38.5	16.2	16.2	17.9	18.2	10
34	2	0.3	33.2	33.2	33.4	33.9	16.0	16.1	17.8	19.0	15
35	1	10.8	65.7	68.1	70.7	70.9	26.2	26.3	38.2	40.7	20
35	2	5.9	65.3	65.3	68.4	68.6	26.3	26.4	30.4	30.9	13
36	1	5.7	35.8	35.8	45.9	48.4	30.4	30.6	39.8	42.4	19
36	2	5.3	38.4	39.9	44.6	44.8	41.6	41.8	47.7	48.6	23
37	1	1.8	63.3	65.5	67.3	67.5	31.4	31.5	38.0	38.6	38
37	2	2.3	50.7	52.4	54.1	54.3	20.2	20.3	22.8	23.2	19
38	1	-6.0	44.1	45.6	46.5	46.7	15.2	15.3	14.7	14.9	0
38	2	-6.4	44.5	46.0	47.5	47.6	23.2	23.3	23.2	23.6	13
39	1	-1.5	45.2	45.3	46.4	47.1	25.7	32.0	30.4	32.3	-2
39	2	1.6	50.6	50.6	48.4	49.1	44.1	54.9	43.1	45.6	37

Table C-7 – Females Standing in Small Heeled Shoes on a Surface Gradient of 30°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	5.0	59.5	59.5	58.6	59.4	35.5	35.7	39.2	39.9	29
21	2	4.0	61.4	61.4	60.3	61.2	44.2	44.3	48.1	48.9	59
22	1										
22	2										
23	1	8.0	52.5	52.5	51.5	52.1	25.2	25.3	27.1	27.6	27
23	2	6.6	59.2	59.2	56.3	56.4	23.4	23.5	24.3	24.7	20
24	1										
24	2										
25	1										
25	2										
26	1	5.9	26.3	26.3	22.1	22.3	33.2	33.4	36.6	37.3	18
26	2	5.3	27.0	28.0	22.8	24.8	31.0	31.2	34.8	35.4	13
27	1										
27	2										
28	1										
28	2										
29	1	6.5	64.2	64.2	63.2	64.2	35.0	43.6	36.7	39.0	15
29	2	5.4	62.1	62.1	62.2	63.1	28.7	35.6	37.0	39.3	14
30	1	20.4	46.1	47.9	43.9	47.7	25.5	35.4	36.9	39.3	32
30	2	15.6	39.6	41.1	38.4	41.7	27.2	37.8	41.0	43.6	33
31	1	0.5	52.5	52.5	48.2	48.9	34.3	47.7	47.5	50.6	21
31	2	-1.6	55.2	57.0	53.9	54.0	33.0	33.2	36.5	37.1	-10
32	1	2.9	63.5	63.5	62.2	63.2	16.3	16.3	20.2	20.6	15
32	2	1.3	50.6	52.6	47.5	51.7	40.6	50.6	37.3	53.3	24
33	1	3.6	63.0	65.2	59.5	59.6	35.2	43.8	31.0	44.3	17
33	2	3.4	45.7	47.3	44.2	44.3	17.2	21.4	15.5	22.0	16
34	1	1.5	40.7	40.7	41.3	41.8	18.1	18.2	21.4	21.8	12
34	2	-2.3	37.1	37.1	37.4	37.9	42.1	52.5	36.0	51.4	12
35	1										
35	2										
36	1	14.0	37.9	37.9	45.8	46.0	37.5	37.7	48.4	51.6	34
36	2	13.0	41.9	41.9	49.0	49.2	38.7	38.9	48.4	49.2	31
37	1										
37	2										
38	1	-2.3	48.1	49.7	50.4	50.5	18.2	18.3	18.0	18.3	12
38	2	-5.8	46.0	47.6	47.6	47.8	22.4	22.5	22.4	22.8	11
39	1										
39	2										

Table C-8 – Females Standing in Small Heeled Shoes on a Surface Gradient of -5°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	1.8	55.8	55.8	56.0	56.8	33.5	33.6	36.5	37.2	26
21	2	3.7	63.4	63.4	62.2	63.1	22.2	22.3	25.1	25.5	26
22	1	12.6	63.9	66.1	69.6	69.8	28.4	28.6	31.9	32.4	19
22	2	12.3	62.2	62.2	66.7	66.8	18.2	18.3	24.2	25.7	26
23	1	-0.4	69.6	72.1	65.4	65.6	8.1	11.3	6.0	6.4	-1
23	2	2.8	67.8	70.1	63.5	63.7	11.9	14.8	9.9	14.1	6
24	1	1.1	48.9	48.9	49.4	50.1	29.4	36.6	28.6	40.7	13
24	2	-0.5	48.9	50.6	49.0	49.1	32.6	40.6	31.7	45.2	19
25	1	-0.4	40.5	41.9	41.0	41.1	24.7	34.2	36.7	39.1	17
25	2	-0.4	39.3	39.3	39.1	39.2	20.3	28.2	32.9	35.0	10
26	1	2.2	33.6	34.7	30.3	30.4	39.1	48.8	37.0	52.9	13
26	2	1.9	37.4	37.4	31.8	32.2	26.5	26.6	29.4	29.9	11
27	1	-2.9	26.2	26.2	28.1	28.4	17.1	17.2	24.1	25.6	6
27	2	0.1	39.9	39.9	44.5	45.1	13.1	13.2	25.7	27.4	7
28	1	4.0	67.6	67.6	72.8	72.9	39.7	39.9	44.2	45.0	16
28	2	5.7	73.2	73.2	77.9	79.1	41.7	41.9	47.5	48.3	14
29	1	6.0	52.0	52.0	55.0	55.1	24.5	30.5	18.0	25.6	-21
29	2	4.3	58.3	58.3	61.0	61.8	27.1	27.2	30.6	31.1	9
30	1	-1.5	33.9	33.9	31.3	31.7	23.9	33.2	35.7	38.1	19
30	2	-0.1	35.9	37.3	34.3	34.7	26.1	26.2	37.5	40.0	19
31	1	-1.7	50.3	50.3	47.0	47.6	16.1	20.1	20.3	21.6	13
31	2	-3.5	54.5	54.5	51.8	52.5	17.8	22.1	12.5	17.8	33
32	1	7.1	51.2	53.3	48.5	52.9	30.9	38.5	31.4	32.0	25
32	2	5.6	58.1	58.1	58.9	59.8	39.6	39.8	41.6	42.3	14
33	1	3.1	38.0	38.0	38.3	38.4	29.8	37.1	30.7	31.3	25
33	2	4.7	41.9	41.9	41.8	41.9	33.0	41.0	33.1	33.7	17
34	1	1.5	48.4	48.4	46.9	47.5	21.3	21.4	23.9	24.3	10
34	2	4.4	33.3	33.3	35.0	35.4	13.9	19.2	22.7	24.1	14
35	1	8.2	67.8	67.8	71.4	71.5	43.1	43.3	47.0	47.8	20
35	2	6.8	70.0	70.0	72.9	73.1	21.1	21.2	23.7	24.1	14
36	1	2.1	35.2	35.2	43.9	44.0	37.4	37.5	45.5	46.3	18
36	2	-0.6	36.7	36.7	48.6	51.3	33.5	33.6	43.3	44.0	13
37	1	3.8	50.9	52.7	55.4	55.6	28.3	28.4	33.7	34.3	30
37	2	3.7	49.6	51.4	57.1	57.3	15.6	17.1	19.2	19.2	5
38	1	-4.4	43.8	45.2	46.1	46.2	28.5	28.6	26.8	27.3	11
38	2	-3.4	49.9	51.6	53.1	53.3	25.5	31.8	21.7	30.9	4
39	1	2.4	44.3	44.3	41.1	41.7	47.4	59.1	48.8	49.7	40
39	2	1.2	53.0	53.0	50.9	51.7	51.9	52.1	57.8	58.9	17

Table C-9 – Females Standing in Small Heeled Shoes on a Surface Gradient of -10°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	1.7	57.1	57.1	57.2	58.0	42.6	42.7	47.7	48.6	34
21	2	-1.0	55.5	55.5	55.1	55.9	32.6	32.7	35.9	36.6	24
22	1	11.8	63.9	66.1	71.8	72.0	29.3	29.4	33.1	33.6	15
22	2	10.9	65.0	65.0	71.9	72.1	18.1	18.2	22.7	23.1	17
23	1	6.3	61.1	63.2	60.2	60.4	25.9	26.0	27.8	28.3	21
23	2	5.6	72.9	75.5	69.8	70.1	24.5	30.5	23.5	23.9	15
24	1	1.0	43.8	43.8	45.0	45.1	67.8	85.2	61.9	89.7	23
24	2	-0.2	50.9	50.9	47.4	48.1	29.5	29.6	34.5	35.1	21
25	1	1.1	44.8	46.3	44.7	44.8	20.8	28.9	29.9	31.8	8
25	2	2.7	35.7	35.7	35.2	35.7	22.1	27.5	29.2	31.0	11
26	1	2.3	53.6	53.6	47.5	48.1	29.5	36.7	28.3	40.3	19
26	2	2.8	33.3	33.3	31.0	31.5	32.6	32.7	36.9	37.5	21
27	1	-0.3	35.2	35.2	38.8	39.4	17.1	17.2	25.3	26.9	8
27	2	-2.7	35.5	35.5	37.6	38.2	11.1	11.1	21.9	23.4	5
28	1	4.8	77.1	77.1	79.2	80.5	47.7	47.9	53.0	54.0	22
28	2	3.4	75.9	76.0	80.3	81.6	49.8	50.0	55.8	56.8	6
29	1	5.2	55.9	55.9	58.7	58.8	25.1	25.2	31.5	32.0	17
29	2	6.9	60.3	60.3	61.5	62.3	27.1	27.2	32.2	32.8	36
30	1	-1.6	36.7	36.7	35.1	35.6	29.1	40.4	41.6	44.3	19
30	2	-1.5	31.6	31.6	29.8	30.2	24.0	33.2	36.7	39.1	19
31	1	-5.1	57.0	59.0	56.2	56.4	26.6	33.1	28.3	28.8	-11
31	2	-1.7	52.5	52.5	48.0	48.6	45.3	56.5	41.1	58.8	34
32	1	6.1	67.8	70.6	63.6	69.2	33.1	41.2	30.3	43.3	20
32	2	4.2	47.9	49.8	46.1	46.7	25.8	25.8	27.0	27.5	22
33	1	2.1	42.9	44.6	40.4	41.0	26.4	26.5	29.5	30.1	20
33	2	5.7	57.5	59.5	55.5	55.6	35.5	35.6	35.6	36.3	19
34	1	6.8	43.8	43.8	45.1	45.7	20.6	20.7	22.9	23.3	8
34	2	5.4	34.3	35.6	35.9	36.4	15.3	19.0	24.0	25.6	13
35	1	10.7	66.5	66.5	68.8	69.0	47.3	47.5	53.4	54.3	17
35	2	8.6	64.2	64.2	66.8	67.0	52.5	52.7	55.2	56.2	24
36	1	-0.3	31.3	31.3	41.2	43.5	35.5	35.7	45.6	46.4	20
36	2	2.3	39.1	40.4	47.0	47.1	38.3	38.5	46.5	47.3	23
37	1	1.6	62.7	64.9	67.0	67.2	34.0	42.4	37.9	38.6	16
37	2	2.5	56.8	58.8	60.6	60.8	27.2	27.3	32.3	32.8	48
38	1	-7.0	35.7	36.9	38.6	38.7	24.4	24.5	23.4	23.8	7
38	2	-8.2	43.6	45.1	46.2	46.3	19.3	19.3	17.7	18.0	9
39	1	1.6	44.1	45.9	41.8	42.4	37.5	37.6	43.3	44.1	36
39	2	-1.6	53.1	53.1	48.8	49.5	34.7	38.0	33.9	43.2	14

Table C-10 – Females Standing in Small Heeled Shoes on a Surface Gradient of -15°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.5	59.8	59.8	59.1	60.0	31.2	31.4	31.2	31.7	11
21	2	1.7	60.2	60.2	60.3	61.2	47.6	47.8	50.4	51.3	31
22	1	11.2	54.4	56.3	64.9	68.5	19.0	19.1	20.4	20.7	14
22	2	8.9	64.1	66.4	70.6	70.9	16.2	16.2	20.4	20.8	19
23	1	4.4	65.0	65.0	61.7	62.5	22.4	27.9	22.4	22.8	14
23	2	5.8	54.6	54.6	52.2	52.9	20.2	20.3	21.9	22.3	12
24	1	-1.8	42.8	42.8	45.0	47.4	36.4	45.2	32.5	46.4	22
24	2	1.3	47.7	47.7	46.5	47.1	26.5	26.6	30.9	31.4	18
25	1	-0.4	40.2	41.6	43.1	45.4	27.4	38.1	39.4	42.0	17
25	2	0.5	42.5	43.9	44.2	44.4	24.9	34.6	37.1	39.5	13
26	1	1.6	45.1	46.6	43.6	43.8	36.8	45.9	35.8	51.2	10
26	2	2.6	35.4	35.4	32.8	33.2	31.3	31.4	35.7	36.3	16
27	1	-1.4	29.9	31.0	33.4	33.4	10.0	10.1	22.9	38.3	6
27	2	0.4	40.3	40.3	42.8	43.5	10.1	10.1	21.9	23.3	7
28	1	3.9	71.4	71.4	75.4	75.6	46.7	46.8	51.1	52.0	16
28	2	5.6	69.2	69.2	72.6	72.7	44.4	44.6	48.6	49.5	9
29	1	6.8	57.3	57.3	58.0	58.8	31.2	31.4	35.9	36.6	33
29	2	6.5	51.6	51.6	55.6	56.3	19.1	19.2	23.0	23.4	-1
30	1	-0.4	43.2	43.2	42.4	43.0	27.0	27.1	36.3	38.7	15
30	2	1.7	42.1	42.1	39.8	40.3	26.6	36.9	38.3	40.8	20
31	1	-3.6	59.5	61.7	52.8	57.2	18.7	23.2	21.6	23.0	28
31	2	3.8	24.8	24.8	25.9	26.2	16.4	22.7	23.2	24.7	23
32	1	7.4	60.5	60.5	60.2	61.2	32.5	32.7	33.7	34.3	18
32	2	9.0	62.5	62.5	60.5	61.4	25.6	31.8	25.4	25.9	13
33	1	4.3	35.4	41.0	37.8	41.0	6.0	6.1	15.1	25.3	-7
33	2	6.6	57.0	59.0	55.7	55.9	35.5	35.7	35.0	35.6	16
34	1	-1.7	54.7	54.7	54.4	55.2	10.7	12.1	15.0	15.0	9
34	2	1.8	41.7	41.7	41.2	41.8	19.2	19.2	22.4	22.8	11
35	1	11.3	68.9	68.9	72.7	72.8	52.3	52.6	54.5	55.5	17
35	2	10.7	60.7	60.8	64.3	65.2	34.4	34.5	40.9	43.5	21
36	1	2.4	38.0	39.3	45.4	45.5	39.4	39.5	49.1	49.9	21
36	2	1.8	36.4	37.7	46.5	46.6	34.4	34.5	43.2	43.9	18
37	1	1.2	59.0	61.1	64.9	65.1	29.5	29.6	35.1	35.8	23
37	2	3.5	57.8	59.8	62.8	63.0	28.4	28.5	33.8	34.3	22
38	1	-7.5	42.2	43.7	45.0	45.1	20.2	20.3	19.6	19.9	10
38	2	-8.9	43.6	45.0	45.9	46.0	19.2	23.9	16.1	23.0	1
39	1	0.9	48.5	48.5	46.1	46.8	37.2	46.3	37.4	39.7	36
39	2	3.6	52.2	54.2	49.8	54.2	40.8	40.9	47.8	48.7	37

Table C-11 – Females Standing in Small Heeled Shoes on a Surface Gradient of -20°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	5.1	59.1	59.1	57.9	58.8	34.5	34.6	39.1	39.8	40
21	2	0.9	61.9	61.9	61.3	62.2	37.3	37.5	40.0	40.7	41
22	1	11.1	61.4	63.6	69.0	69.2	27.4	27.6	30.3	30.8	21
22	2	11.9	64.0	64.0	68.4	68.6	22.3	22.4	26.2	26.6	15
23	1	6.9	61.4	61.4	62.5	62.7	9.1	12.5	11.8	12.5	5
23	2	6.5	63.4	63.4	63.4	64.4	35.2	43.8	33.5	34.1	24
24	1	0.4	44.6	44.6	43.0	43.6	22.9	28.5	26.1	27.8	19
24	2	-1.1	60.9	60.9	56.2	57.0	46.0	46.2	50.5	51.4	21
25	1	-1.3	42.3	42.3	44.0	46.4	21.2	29.5	31.3	33.4	13
25	2	-1.8	39.5	40.8	40.5	40.7	20.3	28.1	30.1	32.0	16
26	1	3.8	21.1	21.1	17.5	18.9	8.5	11.8	15.6	16.6	19
26	2	1.8	33.0	34.1	31.5	31.6	39.9	40.1	42.0	42.7	11
27	1	0.3	46.3	46.3	50.8	51.5	13.1	13.1	25.0	26.7	7
27	2	-0.3	34.8	34.8	32.7	33.1	16.2	16.3	18.6	18.9	17
28	1	3.6	73.8	73.8	76.7	76.9	43.6	43.7	46.4	47.3	6
28	2	3.6	69.4	69.4	73.4	73.6	44.3	44.5	47.3	48.1	3
29	1	3.2	70.5	70.5	73.3	73.6	16.9	16.9	21.1	22.5	-7
29	2	4.5	59.7	59.7	61.0	61.9	26.2	26.3	31.9	32.4	19
30	1	-1.6	45.1	45.1	41.6	42.2	21.9	22.0	27.2	28.9	12
30	2	-1.9	38.4	38.4	37.7	37.8	30.8	30.9	36.1	36.8	12
31	1	-6.3	49.7	51.4	47.9	48.0	32.5	32.7	35.3	35.9	-12
31	2	-3.1	48.1	48.1	44.9	45.5	31.3	43.6	40.9	43.6	15
32	1	7.4	81.4	81.4	80.7	81.9	35.7	44.4	37.1	37.7	16
32	2	7.6	62.6	65.2	61.6	67.1	24.0	29.9	22.8	23.2	12
33	1	1.4	44.2	44.2	41.2	41.7	33.0	33.1	35.7	36.4	15
33	2	4.1	42.1	42.1	41.5	42.1	30.4	30.6	34.2	34.8	12
34	1	6.2	33.5	33.5	35.0	35.5	17.1	17.2	20.4	20.7	11
34	2	-1.3	45.5	45.5	46.4	46.5	23.3	23.4	25.8	26.3	6
35	1	9.7	68.8	71.3	72.5	72.7	44.2	44.4	49.4	50.2	19
35	2	9.8	56.6	58.6	66.5	66.7	32.3	32.5	38.3	38.9	10
36	1	2.1	35.1	35.1	44.8	44.9	35.4	35.5	43.2	44.0	17
36	2	0.9	37.9	37.9	48.0	48.1	37.3	37.5	46.8	47.5	17
37	1	3.8	63.0	65.1	68.2	68.4	23.2	23.3	25.8	26.2	14
37	2	1.7	64.3	66.6	69.2	69.4	24.2	24.3	29.7	30.2	21
38	1	-1.6	41.1	42.4	43.5	43.7	14.4	17.9	11.9	17.0	5
38	2	-1.5	42.7	44.1	45.0	45.1	20.8	25.9	17.2	24.5	7
39	1	1.8	42.0	42.0	40.4	41.0	37.5	37.6	42.1	42.8	29
39	2	2.3	44.1	45.8	41.9	42.5	47.4	47.6	53.5	54.5	31

Table C-12 – Females Standing in Small Heeled Shoes on a Surface Gradient of -25°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	4.9	54.8	57.0	53.7	54.5	40.4	40.6	44.0	44.8	39
21	2	3.6	50.5	52.5	47.5	51.7	47.4	59.1	44.4	63.6	20
22	1	12.3	55.2	57.1	62.7	62.9	19.0	19.1	19.4	19.7	4
22	2	9.9	57.9	57.9	63.4	63.6	18.0	18.0	22.2	23.6	20
23	1	9.4	57.1	57.1	55.3	55.5	19.2	19.3	19.3	19.6	28
23	2	6.6	56.1	56.1	55.2	55.9	19.4	19.5	21.3	21.7	9
24	1	-2.9	50.4	52.2	52.8	53.0	33.1	41.1	29.3	41.8	21
24	2	-0.1	49.0	50.6	48.8	49.0	43.2	43.4	46.1	47.0	19
25	1	-1.2	43.5	50.6	48.7	51.3	27.5	38.2	36.8	39.2	11
25	2	-3.0	48.7	50.4	50.5	50.6	26.7	37.1	36.7	39.1	4
26	1	4.2	45.0	45.1	42.4	43.0	28.9	35.9	27.9	39.8	11
26	2	-2.6	32.4	33.5	32.4	32.5	9.9	9.9	7.6	12.6	11
27	1	0.6	46.6	46.6	46.9	47.6	16.2	16.3	22.1	22.4	15
27	2	0.5	36.2	36.2	37.7	38.2	14.2	14.2	20.1	20.4	13
28	1	5.3	67.5	67.5	74.2	74.4	36.5	36.6	41.1	41.8	1
28	2	1.2	73.8	73.8	76.0	77.1	40.6	40.7	45.8	46.6	2
29	1	5.9	64.9	64.9	65.0	65.9	30.1	30.2	34.5	35.1	22
29	2	6.3	58.4	58.4	59.2	60.1	22.2	22.3	26.8	28.5	29
30	1	-3.4	43.3	43.3	43.7	44.3	43.8	44.0	43.6	44.4	9
30	2	-0.2	33.4	34.6	33.3	36.2	26.9	27.1	31.4	31.9	13
31	1	2.0	40.5	42.0	35.8	38.8	28.0	28.1	39.2	39.8	29
31	2	-5.8	52.7	52.7	48.3	48.9	25.4	25.5	32.1	32.6	20
32	1	2.9	60.2	60.2	59.9	60.9	42.0	52.4	39.2	40.0	11
32	2	4.9	66.4	69.0	62.1	67.5	35.8	36.0	34.1	34.7	10
33	1	-0.3	56.1	58.1	52.7	52.8	28.6	35.5	24.3	34.7	15
33	2	2.7	56.6	58.6	54.2	54.4	30.4	37.8	27.9	28.4	16
34	1	3.9	43.3	43.3	45.1	45.2	20.1	25.0	18.1	25.7	8
34	2	-1.0	49.6	49.6	48.6	48.8	18.1	22.6	20.3	20.7	10
35	1	8.9	56.1	56.1	59.9	60.1	51.1	51.3	52.7	53.6	13
35	2	8.2	65.6	65.6	70.6	70.8	33.3	33.4	38.3	38.9	20
36	1	2.9	38.2	39.5	46.9	47.1	38.5	38.6	44.7	45.4	20
36	2	2.6	46.7	48.3	53.7	53.9	38.5	38.7	47.6	48.4	21
37	1	0.9	56.9	59.0	65.4	65.7	26.1	26.2	31.5	32.1	8
37	2	2.6	51.2	53.0	56.8	57.0	26.1	32.4	28.0	28.5	16
38	1	0.8	44.6	46.1	48.0	48.1	12.3	15.3	9.9	14.0	0
38	2	-1.7	47.6	49.2	50.6	50.8	21.8	27.2	18.2	25.9	4
39	1	0.6	41.3	43.0	39.0	42.4	25.5	31.6	30.7	32.6	36
39	2	1.4	49.7	49.7	49.5	50.2	10.7	10.7	16.0	16.3	23

Table C-13 – Females Standing in Small Heeled Shoes on a Surface Gradient of -30°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.0	51.9	51.9	51.7	52.4	44.7	44.9	46.9	47.8	24
21	2	6.5	58.8	58.8	59.5	60.4	38.7	38.8	41.6	42.4	32
22	1										
22	2										
23	1	4.2	61.0	63.1	61.7	61.9	22.0	22.1	21.8	22.1	-8
23	2	5.3	52.3	52.3	52.4	53.1	15.1	15.2	20.6	21.9	11
24	1										
24	2										
25	1										
25	2										
26	1	2.1	39.3	40.8	37.9	41.2	23.4	23.5	26.6	27.1	14
26	2	2.7	43.9	43.9	42.2	42.8	27.2	33.9	26.1	26.6	9
27	1										
27	2										
28	1										
28	2										
29	1	6.1	62.5	62.5	62.0	62.9	34.5	34.6	40.4	41.1	20
29	2	2.3	70.0	70.0	69.7	70.7	13.9	17.3	11.1	18.5	3
30	1	-2.7	44.6	44.6	45.0	45.1	23.9	24.0	29.3	29.8	7
30	2	-2.2	47.0	48.5	45.6	45.7	31.9	32.0	36.9	37.5	13
31	1	-7.0	41.6	41.6	40.6	41.1	23.8	26.0	25.6	32.5	12
31	2	-7.5	54.6	54.6	50.4	51.1	22.0	30.5	30.5	32.5	-1
32	1	5.2	52.1	54.2	50.7	55.2	30.7	30.8	31.2	31.8	12
32	2	4.1	57.1	57.1	57.5	58.3	25.3	25.4	26.6	27.0	24
33	1	2.4	40.0	40.0	42.4	42.5	28.4	28.5	29.0	29.5	10
33	2	5.4	40.6	40.6	43.1	45.4	24.2	24.3	27.1	27.6	14
34	1	0.9	36.2	37.5	39.8	39.9	22.1	22.2	23.7	24.1	9
34	2	-1.2	29.4	30.4	35.1	35.2	15.2	18.9	11.4	16.3	2
35	1										
35	2										
36	1	5.7	38.3	38.3	46.7	46.8	33.4	33.6	41.9	42.7	24
36	2	2.5	45.7	47.3	51.9	52.1	41.7	41.8	48.8	49.6	24
37	1										
37	2										
38	1	-6.3	38.0	39.3	39.9	40.0	12.8	14.0	10.0	12.7	10
38	2	-4.3	44.0	45.5	47.5	47.6	25.0	31.1	22.8	23.2	10
39	1										
39	2										

Table D-1 – Females Standing in High Heeled Shoes on a Surface Gradient of 0°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	1.5	55.4	55.4	55.2	55.9	19.0	19.1	23.9	24.3	32
21	2	3.1	64.5	64.5	62.7	63.6	22.7	28.2	21.1	30.1	14
22	1	7.8	50.8	52.5	57.7	57.9	27.0	27.1	28.0	28.4	22
22	2	12.0	51.7	53.4	56.8	57.0	17.2	17.3	14.8	15.0	9
23	1	7.7	61.9	61.9	63.4	63.5	21.2	21.2	21.8	22.2	9
23	2	6.6	51.7	51.7	51.3	52.0	28.3	28.4	31.1	31.7	28
24	1	8.0	36.2	36.2	35.4	35.8	34.1	34.3	40.1	40.7	24
24	2	0.3	41.6	41.6	43.7	46.0	12.5	15.5	13.6	14.5	17
25	1	3.3	43.0	44.5	43.3	43.4	18.0	24.9	27.0	28.8	14
25	2	3.6	47.9	49.6	49.9	50.1	23.8	29.6	32.2	34.3	11
26	1	3.3	33.0	33.0	30.6	31.0	43.1	53.7	40.8	41.6	15
26	2	5.0	19.9	19.9	15.9	17.2	38.9	48.5	34.8	49.8	17
27	1	-3.1	26.0	26.0	29.9	30.3	11.1	11.2	19.8	21.1	4
27	2	0.4	34.3	34.3	38.6	39.1	4.6	5.0	22.3	30.8	3
28	1	0.7	63.2	63.2	68.7	69.7	32.3	32.4	38.9	39.6	12
28	2	3.3	67.6	67.6	71.1	71.3	44.3	44.5	47.9	48.7	29
29	1	9.5	63.0	63.0	63.5	64.5	20.1	24.9	27.4	29.2	25
29	2	16.9	47.5	47.5	51.1	51.2	23.4	23.5	30.1	30.6	22
30	1	3.3	32.3	33.6	30.7	33.3	23.5	23.6	34.3	36.5	25
30	2	1.2	23.3	24.2	23.4	23.4	27.3	27.4	35.3	37.6	22
31	1	-1.8	59.5	61.5	56.0	56.2	23.0	23.1	29.7	31.7	20
31	2	0.4	51.2	53.1	47.6	51.5	24.2	24.3	30.0	30.5	14
32	1	8.3	48.1	50.2	45.1	49.2	25.2	25.3	29.4	29.9	29
32	2	7.6	57.8	60.2	54.7	59.7	35.4	35.6	39.7	40.4	27
33	1	4.0	29.6	30.7	32.7	32.8	10.6	13.2	16.1	16.4	-15
33	2	5.9	37.1	38.5	40.5	41.0	19.3	19.3	21.6	21.9	12
34	1	5.5	34.0	34.0	36.2	36.7	12.7	17.6	18.3	19.5	10
34	2	0.6	30.9	30.9	32.6	33.1	15.2	15.3	22.2	23.6	12
35	1	6.4	59.1	59.1	62.1	63.0	37.3	37.5	42.5	45.3	15
35	2	8.3	71.1	71.1	75.6	75.8	24.3	33.8	37.2	39.6	14
36	1	-0.2	36.7	36.7	46.9	49.5	29.3	29.5	36.9	37.6	8
36	2	1.4	38.6	38.6	48.0	48.1	27.3	27.5	35.7	38.0	10
37	1	0.8	47.4	49.0	52.8	52.9	14.7	16.0	18.2	18.2	16
37	2	5.4	55.2	57.0	60.2	60.4	18.0	18.0	21.6	21.9	14
38	1	-4.5	43.3	43.3	44.6	45.2	29.8	37.1	26.8	38.3	14
38	2	-0.4	49.1	50.7	52.6	52.7	25.3	25.4	23.3	23.7	11
39	1	3.6	48.6	49.1	50.4	52.0	23.1	24.1	27.5	29.5	14
39	2	4.2	44.1	44.7	45.6	46.4	25.4	27.7	29.9	32.4	18

Table D-2 – Females Standing in High Heeled Shoes on a Surface Gradient of 5°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	0.4	59.0	59.0	57.7	58.5	39.9	49.7	35.5	50.7	14
21	2	1.0	58.6	58.6	58.8	58.9	17.4	19.1	19.3	19.3	21
22	1	8.8	52.5	54.3	57.4	57.5	19.2	19.2	20.5	20.9	8
22	2	12.5	51.3	51.3	55.4	55.6	19.2	19.3	19.6	19.9	15
23	1	4.2	67.8	67.8	64.3	65.2	25.2	25.3	27.1	27.6	17
23	2	7.1	53.6	53.6	51.3	52.0	31.5	31.6	33.9	34.5	47
24	1	3.2	35.2	35.2	36.2	36.3	56.8	71.1	52.2	75.1	23
24	2	2.3	45.1	45.1	44.6	45.2	29.3	29.4	33.7	34.3	16
25	1	0.0	50.4	58.8	53.6	56.5	22.6	22.7	26.4	28.1	15
25	2	0.6	49.9	51.6	50.3	50.4	23.7	29.4	31.4	33.4	10
26	1	4.2	44.5	46.3	41.5	45.2	33.6	41.8	34.5	36.7	12
26	2	2.4	24.4	24.4	23.6	23.9	36.8	45.9	35.1	50.2	12
27	1	-0.3	28.0	28.0	31.6	32.1	11.1	11.2	19.8	21.1	6
27	2	-0.1	35.0	35.0	38.1	38.6	10.1	10.2	19.5	20.7	7
28	1	4.0	65.4	65.4	74.2	74.3	33.0	41.0	45.9	46.7	17
28	2	1.5	66.0	66.0	69.0	69.1	42.6	42.7	47.1	47.9	8
29	1	5.7	64.6	64.7	65.8	66.8	29.2	29.4	34.0	34.6	20
29	2	6.9	70.1	70.1	69.4	70.5	31.8	39.5	37.9	40.2	13
30	1	0.0	34.1	34.1	34.4	34.5	28.9	40.2	40.5	43.1	14
30	2	2.4	31.1	32.3	30.3	30.7	25.6	35.6	37.1	39.5	18
31	1	-1.2	53.6	53.6	48.6	49.3	21.1	21.2	27.6	29.4	21
31	2	-2.7	47.6	49.2	48.1	48.3	35.8	35.9	39.8	40.5	-10
32	1	5.3	57.0	59.3	54.5	59.3	33.5	41.7	34.7	35.3	15
32	2	5.4	50.9	52.9	48.5	52.7	38.0	47.4	33.9	48.5	18
33	1	4.5	43.5	45.1	43.4	43.6	15.2	15.3	16.9	17.2	-4
33	2	2.1	57.0	59.0	55.2	55.3	32.9	41.0	29.2	41.7	20
34	1	-1.1	33.0	33.0	34.2	34.6	12.0	14.9	14.2	15.1	17
34	2	1.6	27.4	27.4	30.1	30.1	10.0	10.1	12.1	12.3	3
35	1	10.6	64.5	64.5	67.1	68.1	39.6	39.8	43.9	44.7	17
35	2	10.2	65.3	65.3	68.8	69.0	16.2	16.2	23.7	25.3	20
36	1	-0.7	33.4	33.4	41.4	41.5	29.1	29.2	35.1	35.7	4
36	2	-0.2	38.1	38.1	47.4	47.5	33.3	33.4	42.4	43.1	14
37	1	5.4	44.7	46.2	47.3	47.4	23.5	29.2	25.1	25.5	35
37	2	-2.3	57.7	59.8	62.1	62.3	24.4	24.5	28.5	30.3	24
38	1	0.2	44.7	52.0	50.4	53.1	7.0	8.7	5.3	7.6	-7
38	2	-1.0	43.7	45.1	47.1	47.2	11.8	14.6	9.2	13.0	-1
39	1	3.5	42.6	44.3	39.5	43.0	34.5	34.6	40.1	40.8	41
39	2	4.0	48.4	50.3	45.4	49.4	33.0	41.1	38.5	39.2	39

Table D-3 – Females Standing in High Heeled Shoes on a Surface Gradient of 10°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.7	49.9	51.9	47.1	47.8	41.0	51.0	43.0	43.9	25
21	2	3.3	55.8	55.8	55.6	56.4	33.7	33.8	37.0	37.7	31
22	1	9.6	46.6	48.1	54.5	54.6	19.3	19.3	19.6	20.0	1
22	2	14.0	47.7	47.7	49.5	49.6	15.5	19.3	14.9	15.8	29
23	1	8.5	56.6	56.6	56.9	57.7	37.8	47.1	37.8	38.5	36
23	2	8.0	56.7	56.7	54.7	55.4	39.4	49.1	38.2	38.9	39
24	1	-0.2	37.1	38.4	42.2	50.3	16.1	16.2	18.5	18.8	-14
24	2	1.8	49.2	49.2	48.6	49.2	33.0	41.1	34.7	35.3	24
25	1	0.4	45.7	47.2	46.3	46.4	21.3	29.5	33.2	35.3	16
25	2	-0.4	45.6	45.6	46.2	46.8	19.3	26.8	30.6	32.6	6
26	1	2.4	27.9	29.0	24.4	26.5	22.6	22.7	27.7	28.2	17
26	2	3.9	29.1	30.2	27.0	29.3	33.5	33.7	36.6	37.2	14
27	1	-0.5	32.9	32.9	37.2	37.7	14.1	14.1	22.5	22.9	8
27	2	-2.4	31.0	32.2	36.5	36.6	17.1	17.2	26.8	27.3	8
28	1	3.4	64.4	64.4	71.7	71.9	44.6	55.6	50.8	51.8	12
28	2	4.9	70.0	70.1	71.8	72.9	47.7	47.9	51.1	52.1	20
29	1	4.7	69.4	69.4	69.4	70.5	31.4	31.5	35.8	36.4	20
29	2	5.8	64.1	64.1	64.5	65.5	34.1	42.4	37.3	38.0	22
30	1	-1.4	44.0	44.0	40.5	41.0	24.2	33.6	35.2	37.5	14
30	2	0.9	31.7	32.9	30.4	33.0	25.7	35.6	37.1	39.6	19
31	1	-6.0	36.0	37.2	34.6	34.7	32.8	36.0	31.8	40.6	13
31	2	-4.2	28.1	29.1	30.2	31.9	28.4	28.5	26.7	27.2	-28
32	1	5.0	59.4	61.8	55.6	60.5	35.2	43.9	32.1	45.8	18
32	2	6.6	51.7	53.8	49.8	54.2	20.2	25.2	19.5	27.8	16
33	1	1.9	47.5	47.5	47.7	48.3	12.9	13.0	13.4	13.6	16
33	2	4.8	45.1	45.2	46.6	47.2	42.1	52.5	40.3	57.6	17
34	1	0.5	23.4	23.4	25.8	26.2	20.0	20.1	23.6	24.0	8
34	2	1.1	29.5	29.5	30.6	31.0	30.3	37.7	27.2	38.8	11
35	1	12.9	78.0	78.0	79.3	79.5	28.3	28.4	40.8	43.5	16
35	2	9.6	58.1	58.1	60.3	61.2	25.6	31.8	35.0	37.3	12
36	1	1.2	36.8	36.8	46.1	48.6	37.1	37.3	43.3	44.1	11
36	2	1.6	43.1	43.1	50.8	50.9	36.5	36.6	45.9	46.7	22
37	1	3.0	50.8	52.7	54.8	57.8	23.3	23.4	25.5	26.0	9
37	2	-1.3	61.0	63.2	65.3	65.5	19.6	22.3	24.2	24.2	6
38	1	2.2	48.9	50.5	52.0	52.1	11.0	12.0	7.4	9.4	8
38	2	-3.9	42.6	44.0	45.0	45.1	18.2	18.3	18.0	18.3	9
39	1	0.5	50.7	50.7	50.2	50.9	16.8	16.9	23.3	23.7	34
39	2	2.0	40.9	42.5	38.8	42.2	46.1	46.3	51.6	52.5	44

Table D-4 – Females Standing in High Heeled Shoes on a Surface Gradient of 15°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	4.9	58.6	58.6	58.6	59.5	49.6	49.8	55.6	56.6	29
21	2	3.8	61.1	61.1	59.7	60.6	62.1	77.8	58.9	85.0	86
22	1	12.0	52.4	52.4	56.6	56.7	18.1	18.2	16.9	17.2	9
22	2	9.8	53.5	53.5	57.7	57.8	21.6	21.7	24.2	25.8	20
23	1	6.7	57.7	57.7	56.4	57.2	33.5	33.6	34.6	35.2	22
23	2	7.1	57.7	57.7	54.6	55.3	30.4	30.6	32.3	32.8	25
24	1	1.6	44.7	44.7	46.6	46.7	26.6	33.1	31.3	31.8	14
24	2	2.2	44.4	44.4	47.6	47.7	42.6	53.1	38.3	54.7	16
25	1	1.1	50.5	52.2	52.6	52.7	34.6	34.8	37.4	38.0	8
25	2	-0.4	39.6	40.9	40.8	40.9	26.3	32.7	32.8	34.9	8
26	1	4.6	36.9	36.9	35.5	36.0	35.7	44.5	36.1	36.8	13
26	2	3.7	27.9	27.9	25.5	25.9	29.8	37.2	29.8	30.3	15
27	1	-1.2	30.4	30.4	33.8	34.3	11.1	11.2	21.4	22.8	7
27	2	-1.6	31.4	31.4	35.5	36.0	10.1	10.1	22.8	24.3	6
28	1	1.1	60.0	60.0	65.0	65.1	42.8	43.0	48.2	49.1	14
28	2	4.1	71.3	71.3	71.2	72.4	36.7	36.9	42.6	43.3	6
29	1	8.6	67.5	70.4	65.3	66.4	41.1	41.3	45.4	46.2	21
29	2	8.9	59.1	59.2	59.9	60.8	38.5	38.6	43.0	43.8	36
30	1	2.2	32.6	34.0	32.2	35.1	32.1	44.6	45.5	48.5	18
30	2	3.6	25.9	30.2	24.0	25.3	16.0	22.1	29.0	30.9	20
31	1	-6.9	42.2	43.6	42.6	42.7	47.2	47.4	51.4	52.3	36
31	2	-3.9	50.6	52.4	49.6	49.7	32.5	32.7	35.9	36.6	-11
32	1	5.4	49.3	51.3	46.2	50.2	36.8	37.0	37.3	38.0	15
32	2	2.6	48.3	50.2	46.0	50.0	33.5	33.6	36.2	36.9	21
33	1	-0.3	60.8	63.0	56.9	60.0	15.2	18.9	13.1	18.7	15
33	2	2.2	55.9	57.9	53.1	53.2	35.2	43.9	31.7	45.3	15
34	1	-2.4	39.3	40.7	39.3	39.4	18.7	23.2	20.0	20.3	14
34	2	2.9	38.7	38.7	38.8	38.9	35.4	35.6	41.3	42.0	17
35	1	8.5	64.1	64.1	67.3	67.5	34.1	34.3	40.1	40.7	22
35	2	9.9	57.3	57.3	59.8	60.7	42.5	42.7	44.1	44.9	15
36	1	2.6	44.3	44.3	51.4	51.5	37.5	37.7	47.2	50.3	22
36	2	3.1	41.4	41.4	49.1	49.2	34.4	34.6	44.0	46.8	18
37	1	1.1	57.9	67.9	61.0	64.5	20.1	20.2	23.1	23.5	3
37	2	1.7	52.8	54.6	56.6	56.8	34.4	34.5	37.8	38.4	29
38	1	-0.8	45.8	47.4	47.7	47.8	15.4	19.2	13.8	14.0	3
38	2	-7.1	42.4	43.9	45.0	45.1	30.4	30.6	31.0	31.5	14
39	1	0.5	43.3	43.3	40.3	40.9	33.6	33.7	37.6	38.2	41
39	2	3.0	38.7	40.2	35.9	39.0	14.6	20.2	28.1	29.9	15

Table D-5 – Females Standing in High Heeled Shoes on a Surface Gradient of 20°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	2.0	54.4	54.4	53.8	54.6	37.4	37.6	38.8	39.5	15
21	2	2.5	55.7	57.8	52.2	56.7	39.1	39.3	44.7	45.4	24
22	1	9.2	60.0	62.1	66.1	66.2	22.3	22.4	24.2	24.6	12
22	2	8.3	63.3	63.3	67.5	67.7	19.8	24.6	22.8	24.2	20
23	1	4.6	54.2	54.2	52.4	53.2	22.3	22.4	25.5	25.9	29
23	2	7.2	54.9	54.9	52.2	53.0	27.3	27.4	29.2	29.7	30
24	1	1.4	42.5	42.5	41.9	42.0	33.6	33.8	37.6	38.3	33
24	2	-2.1	50.5	50.5	53.2	53.3	19.2	19.2	24.3	24.8	16
25	1										
25	2										
26	1	1.8	33.4	33.4	30.9	31.3	35.6	35.7	40.2	40.9	20
26	2	1.1	37.1	37.1	35.7	35.8	36.9	45.9	34.5	49.3	11
27	1	-3.9	25.4	25.4	29.1	29.5	13.1	13.2	22.9	24.5	7
27	2	-1.6	34.8	36.2	37.0	37.0	16.1	16.2	22.3	22.7	11
28	1										
28	2										
29	1	6.3	75.3	75.3	76.4	77.4	36.3	36.5	40.7	41.4	25
29	2	5.0	60.7	60.7	63.1	64.0	22.2	22.3	24.8	25.2	4
30	1	3.8	35.4	36.7	33.4	33.5	22.5	31.3	35.8	38.1	18
30	2	2.5	32.1	33.3	31.8	32.3	22.4	31.0	33.8	35.9	14
31	1	-3.4	51.5	51.5	45.7	46.3	29.7	41.2	40.5	43.1	25
31	2	-1.4	43.8	43.8	41.4	42.0	39.8	40.0	45.7	46.5	22
32	1	5.7	55.7	57.9	54.4	55.3	28.9	36.0	26.5	37.9	15
32	2	4.8	54.8	57.0	51.7	56.3	34.3	34.4	34.8	35.4	15
33	1	-1.7	58.1	60.1	54.6	54.8	13.9	14.0	14.1	14.3	17
33	2	3.4	54.5	54.5	51.6	51.8	36.9	46.0	32.8	46.9	13
34	1	3.1	46.9	46.9	47.6	48.3	18.1	18.2	22.1	22.4	10
34	2	-3.1	43.0	43.0	41.5	42.1	32.0	39.8	29.9	42.7	15
35	1	10.6	61.5	61.5	62.7	63.6	37.0	37.2	45.2	46.0	28
35	2	9.7	70.6	70.6	71.3	71.5	41.2	41.4	42.9	43.6	19
36	1	5.4	37.8	37.8	47.1	47.3	35.3	35.5	45.4	46.2	25
36	2	3.5	44.9	44.9	51.0	51.1	39.5	39.7	47.0	47.8	23
37	1	-0.2	69.0	71.4	70.7	70.9	32.6	32.7	35.3	36.0	16
37	2	1.0	42.9	44.3	49.8	49.9	9.2	10.0	13.1	13.1	12
38	1	-2.5	42.7	44.1	44.8	44.9	28.4	28.5	28.0	28.5	16
38	2	-4.3	43.2	43.2	45.8	45.9	27.4	27.6	27.7	28.2	15
39	1	-1.4	43.1	44.8	38.9	42.3	54.6	54.8	57.0	58.0	40
39	2	3.0	44.2	46.0	41.4	45.1	28.2	28.3	33.9	34.5	17

Table D-6 – Females Standing in High Heeled Shoes on a Surface Gradient of 25°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	4.7	57.6	57.6	55.6	56.4	49.7	49.9	54.1	55.1	32
21	2	1.0	60.0	60.0	59.7	60.6	47.8	59.7	48.4	49.4	39
22	1	10.5	53.3	55.1	60.2	60.3	19.2	19.3	20.2	20.5	8
22	2	9.0	53.8	55.6	59.7	59.8	21.0	21.1	21.4	21.7	9
23	1	5.5	61.1	61.1	60.3	60.4	23.4	23.5	26.6	27.0	23
23	2	8.2	61.2	61.2	59.2	60.0	36.2	45.1	33.6	34.2	34
24	1										
24	2										
25	1										
25	2										
26	1	5.7	41.5	43.2	39.5	43.0	30.5	38.0	30.7	43.7	25
26	2	3.4	27.7	27.7	26.5	26.8	31.6	39.3	30.3	43.3	11
27	1										
27	2										
28	1										
28	2										
29	1	7.5	72.1	72.1	72.7	73.8	21.0	21.1	26.6	28.4	33
29	2	7.6	60.5	60.5	61.5	62.4	29.3	29.4	34.0	34.6	32
30	1	4.2	26.2	27.2	23.6	25.7	18.3	18.4	26.1	26.5	25
30	2	3.7	28.8	29.9	26.1	28.4	20.1	20.2	28.2	28.7	23
31	1	-0.1	57.8	57.8	54.1	54.2	32.5	45.2	42.4	45.2	22
31	2	-3.5	51.3	51.3	47.5	48.2	25.7	35.6	35.3	37.6	19
32	1	4.2	54.8	57.0	52.2	56.9	31.0	38.7	27.3	39.0	15
32	2	5.2	60.8	63.3	58.5	63.7	40.2	40.4	45.5	46.3	23
33	1	2.6	35.8	41.5	34.4	42.6	21.2	21.3	21.9	22.3	23
33	2	2.9	47.0	47.0	46.8	47.0	10.0	12.4	9.0	12.8	19
34	1	2.0	41.5	41.5	43.1	43.2	1.8	2.0	3.8	5.3	4
34	2	-2.0	49.1	49.1	47.7	47.8	32.0	39.8	28.0	39.9	6
35	1	11.4	62.0	62.0	65.6	66.5	43.1	43.3	49.9	50.7	25
35	2	6.7	58.3	58.3	63.4	63.6	26.9	27.0	29.8	30.3	10
36	1	7.4	37.9	38.0	45.7	45.9	39.6	39.7	49.3	50.1	26
36	2	9.7	43.2	44.7	48.4	48.6	41.4	41.6	49.5	50.3	24
37	1	0.9	55.6	57.6	58.9	59.1	33.6	33.7	34.0	34.7	16
37	2	1.2	49.0	50.8	55.5	58.7	31.6	31.7	35.3	35.9	20
38	1	14.3	56.5	58.3	59.4	59.5	25.3	25.4	24.4	24.8	20
38	2	7.1	45.1	45.1	46.9	47.6	27.3	27.4	27.0	27.4	17
39	1	-0.3	36.3	36.3	35.7	36.3	36.6	36.7	41.5	42.2	25
39	2	0.2	40.1	41.7	40.5	41.1	35.1	35.2	41.0	41.7	43

Table D-7 – Females Standing in High Heeled Shoes on a Surface Gradient of 30°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	8.0	55.1	55.1	52.3	53.1	64.2	64.5	66.2	67.4	50
21	2	4.7	52.2	52.2	50.2	51.0	51.5	51.8	55.6	56.6	46
22	1										
22	2										
23	1										
23	2										
24	1										
24	2										
25	1										
25	2										
26	1										
26	2										
27	1										
27	2										
28	1										
28	2										
29	1										
29	2										
30	1	8.2	35.7	37.1	35.7	37.1	36.9	39.3	36.9	39.3	25
30	2	5.2	29.7	30.9	27.2	29.5	23.6	32.7	38.9	41.5	27
31	1										
31	2										
32	1										
32	2										
33	1										
33	2										
34	1	3.7	52.4	54.2	54.5	54.6	5.0	5.1	6.7	7.1	-4
34	2	1.2	41.6	41.6	42.6	43.2	16.2	16.3	19.5	19.8	3
35	1										
35	2										
36	1	17.8	33.9	33.9	40.7	40.8	42.4	42.6	49.5	50.3	38
36	2	19.4	38.2	38.2	44.6	44.7	39.3	39.5	46.5	47.3	36
37	1										
37	2										
38	1	13.2	42.4	43.1	48.3	48.4	26.4	26.5	24.2	26.0	23
38	2	13.2	53.7	55.5	53.7	55.5	18.5	26.3	18.5	26.3	19
39	1										
39	2										

Table D-8 – Females Standing in High Heeled Shoes on a Surface Gradient of -5°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	0.2	56.3	56.3	60.1	60.3	26.7	33.2	24.1	34.4	-24
21	2	3.0	57.6	57.6	58.8	59.6	46.7	46.9	51.8	52.7	23
22	1	9.2	49.2	50.9	57.0	57.2	21.9	22.0	24.5	24.9	14
22	2	12.1	46.4	46.4	50.9	51.0	25.4	25.5	26.7	27.1	22
23	1	6.1	60.7	60.7	60.0	60.1	21.4	21.5	22.4	22.7	21
23	2	6.8	61.7	61.7	61.3	62.1	22.3	22.4	24.8	25.3	26
24	1	1.7	51.7	51.7	52.0	52.1	32.6	40.7	31.0	44.3	24
24	2	-1.0	45.1	46.7	49.3	49.4	25.9	32.3	19.6	27.9	25
25	1	-2.4	42.6	44.1	43.7	43.8	18.8	23.4	28.1	29.9	12
25	2	-1.6	41.9	48.7	46.1	48.6	31.6	31.7	35.7	36.3	15
26	1	5.7	30.6	31.7	29.0	29.1	28.4	28.6	33.5	34.1	15
26	2	3.7	35.7	35.7	34.0	34.4	33.5	33.6	37.8	38.5	15
27	1	-1.4	29.9	29.9	32.8	33.3	7.0	7.0	16.6	27.8	4
27	2	-0.2	29.4	29.4	35.2	35.6	6.0	6.1	22.8	38.2	3
28	1	5.6	62.6	62.6	65.5	66.4	42.7	42.9	48.2	49.1	20
28	2	2.8	69.2	72.0	68.3	69.4	36.3	36.5	42.9	43.6	2
29	1	7.7	67.1	67.1	69.8	69.9	25.4	25.5	28.6	29.1	15
29	2	5.7	59.8	59.8	61.7	61.9	16.1	16.2	18.8	20.0	3
30	1	-0.9	34.3	34.3	35.9	36.4	32.5	32.7	37.5	38.2	6
30	2	-0.8	36.8	38.0	36.2	36.3	35.6	35.8	35.9	36.5	14
31	1	2.0	41.1	41.1	41.1	41.1	18.7	26.5	18.7	26.5	22
31	2	-4.0	35.5	36.7	35.3	35.4	18.2	18.3	23.9	25.4	23
32	1	5.1	52.5	54.6	51.5	56.1	33.1	33.2	39.4	40.1	19
32	2	5.2	54.3	56.5	54.0	58.8	19.5	27.0	35.4	37.7	16
33	1	4.8	49.0	49.0	47.1	47.8	39.3	39.5	40.4	41.1	19
33	2	7.0	40.6	42.2	41.6	42.2	40.5	40.6	43.7	44.5	19
34	1	-2.0	45.2	45.2	44.7	44.9	20.2	20.3	22.8	23.2	4
34	2	1.7	32.7	32.7	35.3	35.8	15.1	15.2	21.8	23.3	12
35	1	9.9	60.7	60.7	65.6	65.8	44.4	44.6	49.5	50.4	13
35	2	10.5	71.9	71.9	73.7	74.7	40.2	40.4	44.1	44.9	8
36	1	1.3	35.5	35.5	44.6	44.7	37.4	37.6	46.2	47.0	19
36	2	1.3	40.4	40.4	50.8	53.7	41.5	41.7	52.5	53.4	22
37	1	4.6	56.3	58.3	60.0	60.2	33.0	41.0	35.7	36.3	29
37	2	0.6	54.3	56.2	61.0	61.1	19.2	19.2	19.2	19.6	0
38	1	0.3	49.0	50.6	52.6	52.7	27.4	27.5	26.7	27.2	12
38	2	0.5	47.3	48.9	50.0	50.1	27.4	27.5	26.4	26.9	13
39	1	3.5	47.2	47.7	48.9	49.8	30.0	32.1	34.2	35.5	14
39	2	2.7	49.3	50.4	51.5	52.8	26.3	27.5	30.4	33.9	14

Table D-9 – Females Standing in High Heeled Shoes on a Surface Gradient of -10°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	3.1	57.6	57.6	56.7	57.5	34.1	42.5	33.8	34.4	22
21	2	3.0	60.4	62.8	57.7	62.8	40.4	50.4	43.7	44.5	24
22	1	10.3	55.6	57.5	62.4	62.6	13.7	15.0	10.5	13.4	3
22	2	11.9	52.7	54.6	59.2	59.4	18.0	22.3	26.6	28.3	16
23	1	6.1	48.0	48.0	47.8	48.5	30.4	30.6	34.2	34.8	30
23	2	7.0	53.8	53.8	52.0	52.7	26.3	26.4	29.8	30.3	33
24	1	1.2	36.8	38.1	40.1	40.3	10.1	11.0	8.4	10.7	-20
24	2	1.9	46.6	46.6	45.0	45.1	30.9	31.1	35.4	36.0	17
25	1	-1.4	51.2	52.9	54.9	57.8	35.7	39.1	38.6	38.6	13
25	2	0.0	54.4	56.3	56.0	56.2	15.6	21.7	25.8	27.5	10
26	1	3.2	44.9	44.9	37.7	38.2	29.7	29.8	32.9	35.0	14
26	2	8.5	24.0	24.9	22.5	24.4	15.3	21.3	23.6	25.2	14
27	1	1.4	42.3	42.3	46.4	47.1	13.3	15.0	19.9	19.9	2
27	2	-2.3	27.0	27.0	31.5	31.9	8.1	8.1	20.5	34.3	2
28	1	2.8	65.7	65.7	67.7	67.9	45.7	45.9	50.1	51.1	21
28	2	5.2	71.0	71.0	75.4	75.6	40.6	40.8	43.2	44.0	16
29	1	8.2	63.8	63.8	64.4	65.4	30.2	30.3	35.6	36.2	32
29	2	5.0	53.6	53.6	56.1	56.9	27.3	27.4	30.5	31.0	22
30	1	3.2	27.4	28.4	25.8	28.1	16.6	23.0	25.3	26.9	16
30	2	-1.5	33.3	33.3	35.4	35.9	34.7	34.9	40.4	41.0	8
31	1	1.1	34.9	34.9	32.5	32.9	12.7	17.6	30.2	32.2	22
31	2	-2.6	42.4	44.0	36.7	39.8	24.3	24.4	31.5	33.6	20
32	1	7.3	60.5	62.8	59.6	64.8	26.9	27.0	31.0	31.6	17
32	2	7.8	68.0	68.0	67.6	68.6	42.6	53.2	38.3	54.9	13
33	1	0.2	50.8	52.6	46.9	49.5	29.4	29.6	28.4	28.9	22
33	2	3.4	38.8	40.4	37.6	38.2	29.3	36.5	27.5	39.2	14
34	1	1.7	30.8	30.8	31.7	32.2	29.0	29.1	31.2	31.7	11
34	2	4.2	27.5	27.5	29.1	29.4	31.0	31.1	31.6	32.1	17
35	1	11.2	61.7	61.7	64.5	64.6	51.4	51.6	53.2	54.2	29
35	2	8.6	68.2	68.2	69.7	70.7	38.9	39.0	41.5	42.3	10
36	1	-0.2	30.6	31.6	40.1	40.2	37.4	37.6	46.5	47.3	17
36	2	2.2	40.9	40.9	49.8	49.9	35.5	35.7	44.7	45.4	17
37	1	0.8	57.1	59.2	64.5	68.1	19.1	19.2	21.4	21.8	2
37	2	0.9	58.2	60.4	63.9	67.5	10.0	11.0	9.9	12.6	3
38	1	-2.2	47.7	49.3	48.7	48.9	14.9	18.5	14.4	14.7	5
38	2	-2.6	50.1	51.8	53.3	53.5	21.3	21.4	20.7	21.1	12
39	1	2.2	46.8	46.8	45.7	46.4	39.6	39.8	44.5	45.3	34
39	2	2.1	49.9	49.9	48.7	49.4	44.2	55.1	42.5	43.3	31

Table D-10 – Females Standing in High Heeled Shoes on a Surface Gradient of -15°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	3.1	52.5	52.5	52.4	53.2	38.3	47.7	40.0	40.8	27
21	2	1.4	64.0	64.0	60.5	61.3	49.5	61.7	48.9	49.8	29
22	1	7.3	56.7	56.7	64.2	64.4	29.3	29.4	33.0	33.6	18
22	2	7.8	52.9	54.8	61.1	61.3	23.1	23.2	24.7	25.1	16
23	1	5.9	58.9	58.9	60.6	60.8	17.3	17.4	19.0	19.3	-4
23	2	6.4	50.5	52.3	50.4	50.5	22.2	22.3	23.9	24.3	5
24	1	2.9	51.7	53.1	53.9	54.6	26.4	28.3	29.6	31.3	15
24	2	3.3	48.8	50.2	49.8	51.0	29.0	30.7	34.3	34.9	13
25	1	-0.8	56.3	58.3	59.6	59.8	27.7	38.4	37.9	40.3	3
25	2	-1.1	52.5	54.3	54.4	54.6	18.8	23.4	24.1	25.7	3
26	1	7.6	33.7	35.0	33.7	35.0	21.5	21.8	21.5	21.8	16
26	2	6.0	19.1	19.2	16.1	17.5	18.7	18.8	24.8	26.6	18
27	1	-2.2	34.0	34.0	35.8	36.3	12.1	12.2	20.8	22.1	4
27	2	-2.0	28.4	28.4	31.7	32.2	5.5	6.0	23.3	32.1	5
28	1	6.5	75.5	75.5	76.5	76.7	39.2	39.4	44.1	44.9	8
28	2	1.8	64.0	64.0	66.0	67.0	41.4	41.6	47.6	48.4	8
29	1	8.9	61.6	61.6	63.7	63.9	30.2	30.3	34.6	35.2	27
29	2	6.0	58.8	58.8	60.1	60.9	17.5	21.7	29.0	30.9	35
30	1	0.3	36.5	36.5	37.8	38.4	35.6	35.7	38.0	38.6	11
30	2	-0.7	33.9	33.9	33.8	34.3	35.5	35.7	37.6	38.3	12
31	1	-1.0	61.0	63.4	54.3	59.0	15.3	21.2	22.7	24.1	20
31	2	-1.5	54.3	54.3	51.0	51.7	21.9	22.0	27.4	27.8	15
32	1	1.9	58.6	61.0	56.4	61.4	30.4	37.9	27.9	39.8	8
32	2	8.3	42.4	44.0	42.8	43.4	26.7	26.8	27.0	27.5	15
33	1	2.3	43.5	43.5	42.8	43.4	28.2	28.3	28.4	28.9	14
33	2	1.7	57.6	57.6	54.9	55.5	23.9	29.8	27.1	28.8	16
34	1	-0.5	51.7	53.6	52.0	52.2	41.7	42.0	38.8	39.4	14
34	2	0.3	37.8	37.8	38.7	39.2	24.1	24.2	26.3	26.8	7
35	1	8.1	61.5	63.6	67.3	67.4	32.0	32.1	36.4	37.0	3
35	2	9.1	66.0	68.4	72.0	72.2	48.5	48.7	52.0	52.9	8
36	1	2.5	35.4	35.4	47.5	50.2	37.3	37.5	47.1	47.9	16
36	2	2.7	40.4	41.8	51.7	54.6	35.5	35.6	46.8	47.6	19
37	1	4.8	74.8	77.4	77.3	77.6	15.0	15.1	16.7	17.0	4
37	2	1.1	53.7	55.5	57.6	57.8	24.3	24.4	27.5	27.9	22
38	1	1.4	45.0	46.5	47.7	47.9	22.3	22.4	20.4	20.8	9
38	2	9.0	48.2	49.8	50.6	50.7	8.5	10.6	5.7	8.1	6
39	1	0.1	43.4	43.4	41.3	41.9	33.6	33.8	39.9	40.6	28
39	2	-0.4	45.9	45.9	45.7	46.4	44.8	44.9	49.2	50.1	32

Table D-11 – Females Standing in High Heeled Shoes on a Surface Gradient of -20°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	1.6	61.1	61.1	60.7	61.6	29.3	29.5	33.1	33.7	18
21	2	2.7	46.2	48.0	44.1	47.8	39.5	39.7	44.7	45.5	26
22	1	13.2	46.0	47.6	51.8	51.9	19.3	19.3	19.0	19.3	7
22	2	13.8	53.4	55.2	60.4	60.5	14.0	14.0	16.4	16.6	24
23	1	4.4	52.9	52.9	52.9	53.6	17.1	17.2	21.4	21.7	31
23	2	5.1	47.1	47.1	48.4	49.1	14.1	14.1	20.3	20.6	33
24	1	-2.5	41.0	47.7	44.9	47.3	29.4	36.6	27.9	39.8	9
24	2	-1.1	38.9	40.3	46.2	55.3	20.3	20.4	20.4	20.7	-11
25	1										
25	2										
26	1	4.8	31.0	31.0	29.5	29.9	24.3	24.4	28.5	29.0	11
26	2	4.6	33.0	38.3	30.2	37.4	16.5	16.6	20.8	21.2	14
27	1	-1.0	26.9	26.9	31.3	31.7	3.7	4.0	25.6	35.4	4
27	2	1.3	33.4	33.4	38.8	39.3	8.0	8.1	24.6	41.3	6
28	1										
28	2										
29	1	7.1	66.7	66.7	68.0	69.0	29.9	30.0	34.7	35.2	38
29	2	8.5	62.0	62.0	62.5	63.5	22.1	22.2	28.5	29.0	44
30	1	0.6	40.4	41.9	39.8	39.9	30.7	30.8	34.4	35.0	10
30	2	-2.3	34.1	34.1	36.9	44.0	33.7	33.9	38.4	39.1	9
31	1	-1.1	47.5	47.5	47.8	50.2	26.3	26.4	28.8	29.3	-18
31	2	-1.5	63.8	63.8	59.0	59.8	14.1	19.5	21.1	22.5	6
32	1	3.5	58.0	58.0	59.5	60.4	25.4	25.5	27.9	28.4	23
32	2	5.1	58.1	58.1	56.6	57.4	37.3	46.5	33.5	47.8	15
33	1	0.8	56.6	66.0	55.6	58.7	22.2	22.3	21.9	22.3	7
33	2	2.8	42.0	48.6	41.8	44.0	26.9	33.4	23.2	33.1	20
34	1	1.6	40.6	42.0	42.4	42.5	29.9	37.2	25.6	36.4	8
34	2	-2.5	42.9	44.4	45.5	45.6	18.0	18.1	22.8	24.3	8
35	1	10.8	55.9	57.9	62.2	62.4	27.8	38.4	39.8	42.3	8
35	2	10.3	67.5	69.7	73.7	73.9	42.4	42.6	49.5	50.4	10
36	1	6.8	47.4	49.1	53.5	53.7	31.9	39.6	43.6	46.4	25
36	2	2.7	38.8	40.1	47.7	47.8	41.5	41.7	48.9	49.8	23
37	1	3.4	75.0	77.7	78.8	79.1	23.0	23.1	23.7	24.1	-5
37	2	1.4	63.2	65.5	68.9	69.2	15.9	16.0	18.0	18.3	0
38	1	0.8	53.3	55.1	55.8	56.0	10.1	11.0	8.4	10.7	6
38	2	1.5	40.6	42.0	42.5	42.7	23.3	23.4	21.1	21.5	11
39	1	1.2	40.7	40.7	38.7	39.3	26.2	26.3	30.7	31.2	29
39	2	2.4	46.0	46.0	47.1	47.8	23.3	23.4	27.4	27.9	8

Table D-12 – Females Standing in High Heeled Shoes on a Surface Gradient of -25°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	0.8	55.0	55.0	55.4	56.2	16.2	16.2	19.1	19.5	-4
21	2	2.2	56.2	56.2	57.5	58.3	42.6	42.8	45.2	46.0	25
22	1	10.4	48.4	48.4	56.8	57.0	17.1	17.2	19.2	19.5	2
22	2	9.2	46.5	48.2	52.8	53.0	16.1	16.1	16.5	16.8	4
23	1	6.6	48.9	48.9	48.4	49.1	22.2	22.3	24.8	25.2	11
23	2	1.8	50.0	50.0	51.6	51.8	7.4	10.2	11.4	12.1	6
24	1										
24	2										
25	1										
25	2										
26	1	4.0	61.3	61.3	55.9	56.7	15.5	15.6	17.8	18.2	10
26	2	1.2	28.9	29.9	26.9	27.0	16.2	16.3	19.8	21.1	10
27	1										
27	2										
28	1										
28	2										
29	1	7.4	61.1	61.1	61.5	62.4	20.8	20.9	26.5	28.2	24
29	2	4.5	68.8	68.8	68.7	68.8	29.3	29.4	30.8	31.3	7
30	1	-1.7	44.0	45.6	45.3	45.5	31.7	31.8	35.4	36.0	12
30	2	0.9	33.1	34.3	35.2	35.3	30.8	30.9	34.9	35.5	8
31	1	4.0	24.3	24.3	23.3	23.6	15.6	19.4	30.7	32.7	30
31	2	-2.4	33.0	33.0	30.9	31.3	49.1	49.4	54.6	55.5	29
32	1	1.5	49.3	49.3	48.9	49.6	29.4	36.6	26.2	37.4	5
32	2	2.4	47.6	49.5	45.8	49.8	42.5	53.0	42.1	42.9	23
33	1	1.5	31.1	31.1	32.7	32.8	35.7	44.5	32.9	33.5	16
33	2	1.3	48.2	49.8	48.1	48.2	13.2	13.3	14.2	15.1	12
34	1	5.4	29.6	30.6	31.6	31.7	7.9	10.9	11.2	11.9	10
34	2	-2.4	50.5	50.5	50.5	50.6	22.1	22.2	24.4	24.8	5
35	1	11.8	68.6	71.1	74.2	74.4	35.3	35.5	41.0	41.7	15
35	2	10.7	57.2	57.2	66.7	66.9	34.0	42.3	45.7	48.7	7
36	1	7.3	39.5	39.5	48.2	48.3	37.4	37.6	45.9	46.7	33
36	2	4.8	46.5	48.1	51.3	51.5	43.7	43.9	50.1	51.0	19
37	1	2.6	67.2	69.6	70.6	70.8	11.2	11.3	13.6	13.9	-1
37	2	0.6	78.0	80.9	81.8	82.1	10.9	11.0	17.2	17.5	7
38	1	3.1	47.3	48.8	49.8	50.0	18.3	18.3	14.4	20.4	7
38	2	0.2	42.9	44.3	45.7	45.8	26.1	32.4	23.5	24.0	11
39	1	2.4	41.9	43.6	39.8	40.4	29.8	37.2	31.7	32.3	25
39	2	-1.9	39.2	39.2	37.0	37.5	17.8	17.9	21.1	21.4	25

Table D-13 – Females Standing in High Heeled Shoes on a Surface Gradient of -30°

Subject	Measurement	Thoracolumbar Offset	Shoun T1-T12	Leroux T1-T12	Shoun T1-L1	Leroux T1-L1	Shoun L1-L5	Leroux L1-L5	Shoun T12-L5	Leroux T12-L5	Sacrum
21	1	3.0	53.2	53.2	51.8	52.5	24.5	30.4	23.8	24.2	7
21	2	1.9	54.0	56.2	51.5	56.1	49.3	49.6	53.8	54.7	24
22	1										
22	2										
23	1										
23	2										
24	1										
24	2										
25	1										
25	2										
26	1										
26	2										
27	1										
27	2										
28	1										
28	2										
29	1										
29	2										
30	1	-4.4	44.3	44.3	46.9	47.0	35.5	35.6	38.5	39.2	0
30	2	-5.7	42.1	42.1	44.6	53.2	31.8	31.9	37.8	38.4	2
31	1										
31	2										
32	1										
32	2										
33	1										
33	2										
34	1										
34	2										
35	1										
35	2										
36	1	3.3	43.3	43.3	52.1	52.3	40.6	40.7	49.6	50.5	25
36	2	6.5	47.2	47.2	55.2	55.3	40.4	40.6	48.5	49.3	27
37	1										
37	2										
38	1	-0.5	42.6	44.0	45.2	45.3	19.3	19.4	16.8	17.1	5
38	2	0.5	47.4	49.0	50.0	50.2	24.5	30.5	21.0	29.9	9
39	1										
39	2										

Appendix 2

The following appendix contains details about the software written for this thesis.

The first item is the class diagram showing the classes, their methods and attributes and their associations to each other.

The second item is the database schema, showing how database entities are related.

Finally, there are some screenshots of the software.

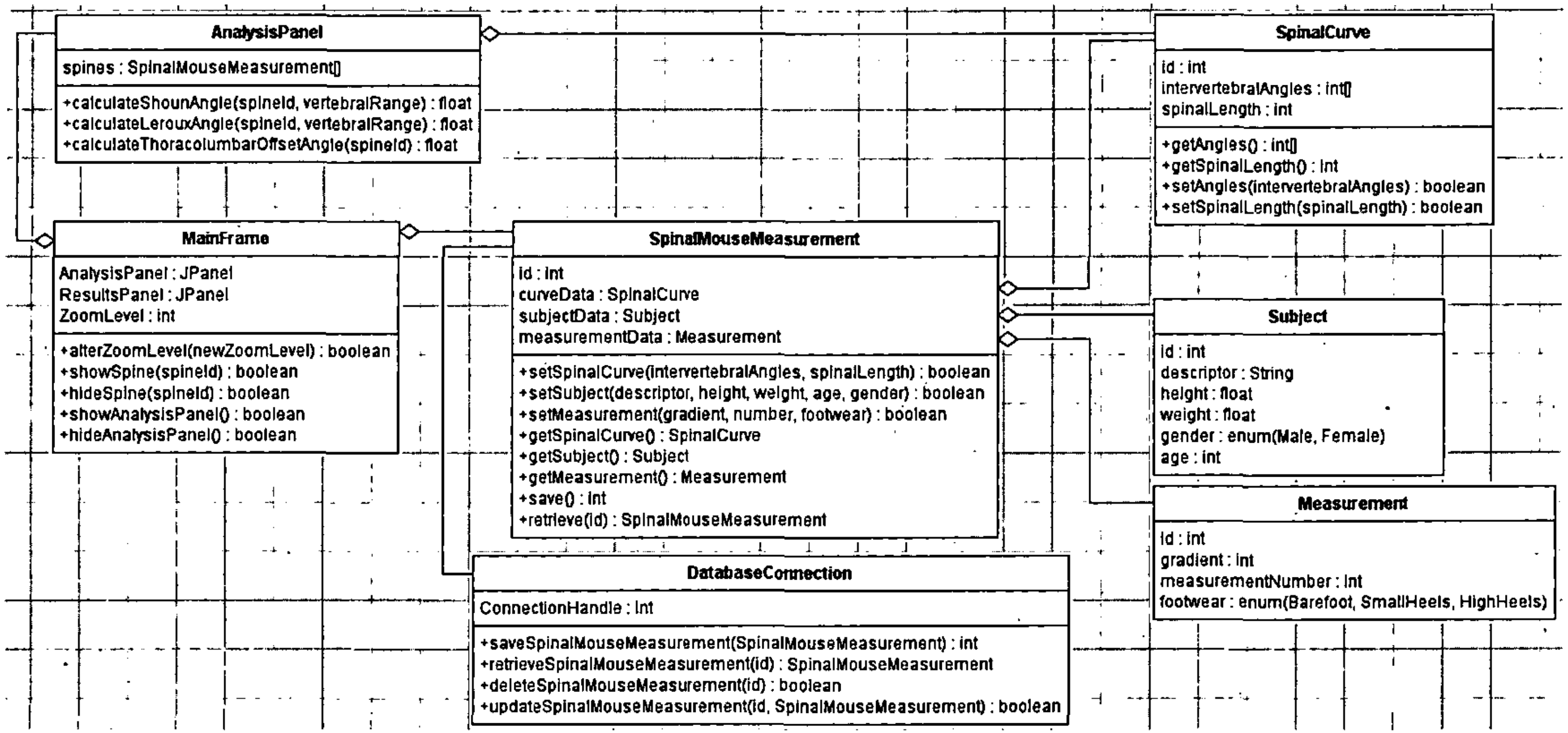

Figure E-1 – Class Diagram

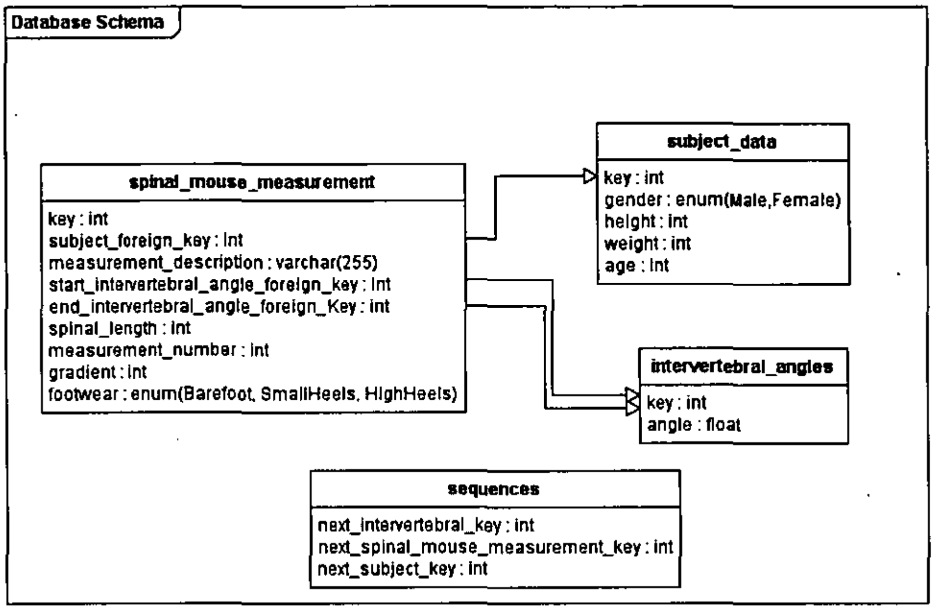

Figure E-2 – The Database Schema

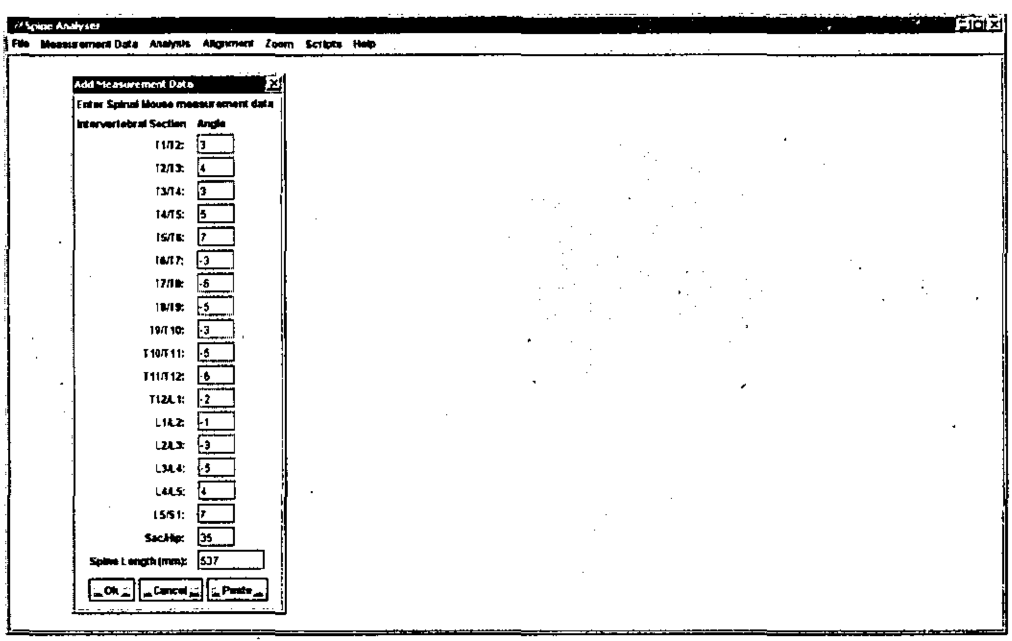

Figure E-3 – Entering the SpinalMouse® data

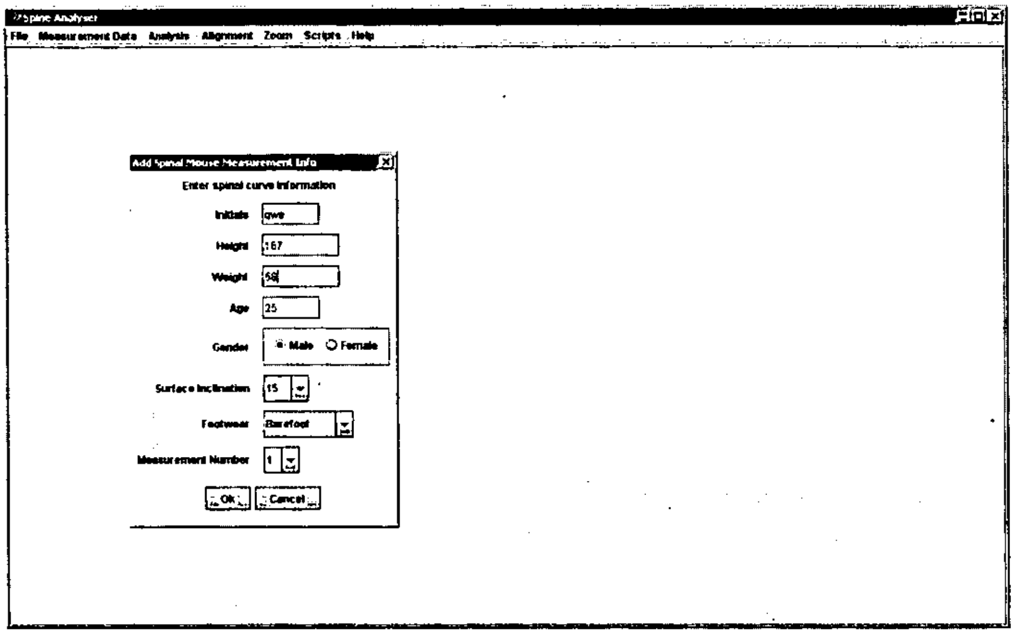

Figure E-4 – Saving the measurement information

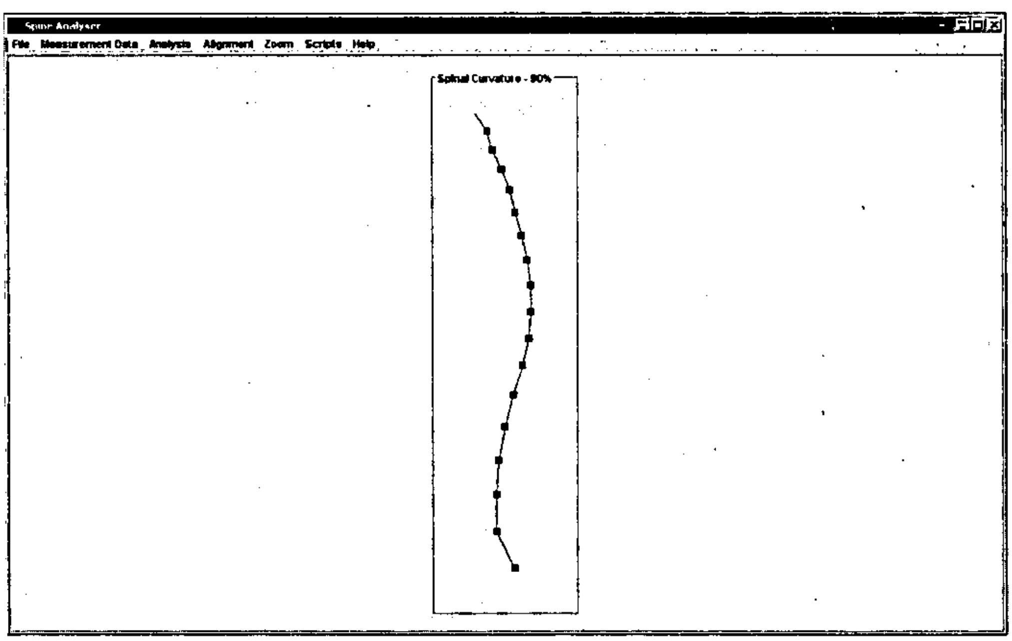

Figure E-5 - Displaying the spinal curve

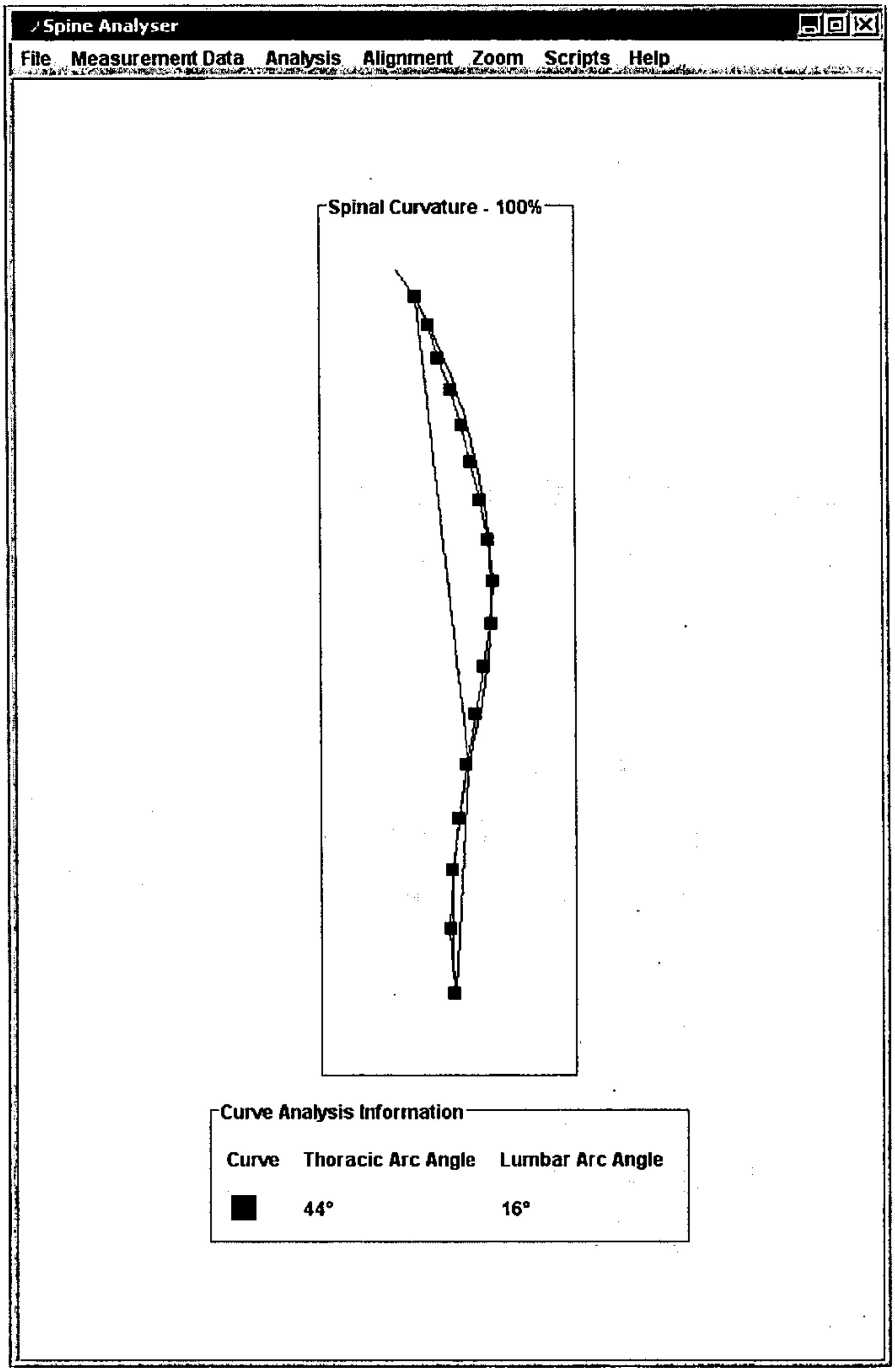

Figure E-6 – Calculating the Shoun Angle

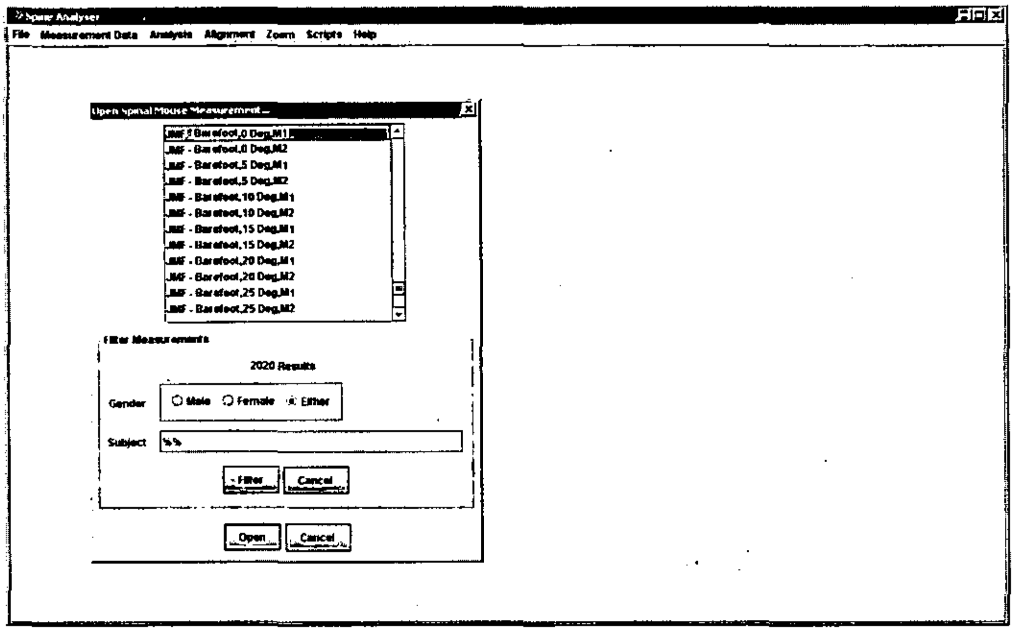

Figure E-7 – Loading spinal contours

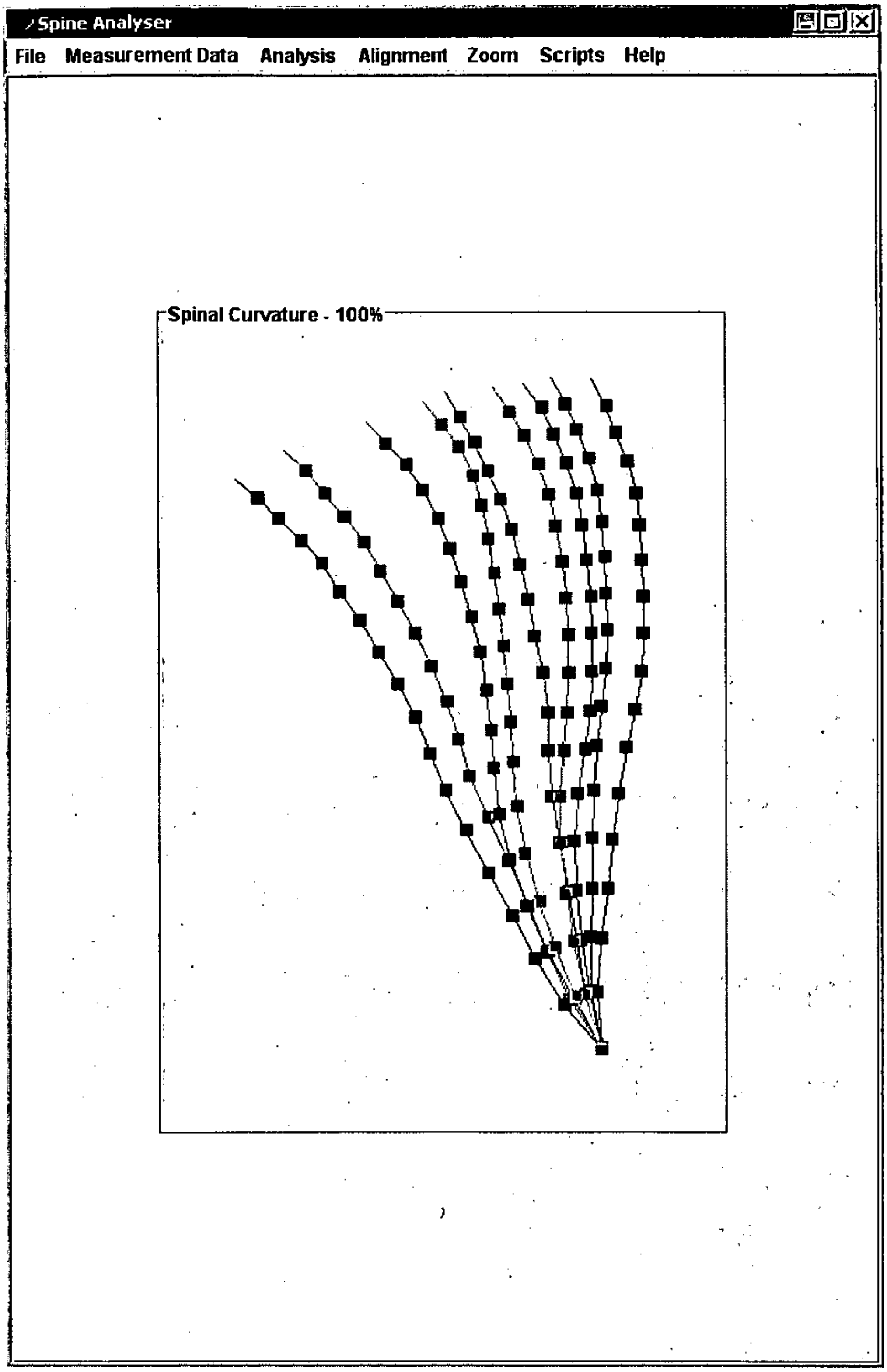

Figure E-8 – Multiple spines on screen