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I am submitting herewith a dissertation written by Traci Lee Haydu entitled "Accuracy of Pelvis Repositioning in Individuals With and Without Low Back Pain." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy with a major in Education.

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We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Interim Vice Provost
and Dean of the Graduate School

ACCURACY OF PELVIS REPOSITIONING IN INDIVIDUALS WITH AND WITHOUT LOW BACK PAIN

A Dissertation Presented

for the

Doctor of Philosophy Degree

The University of Tennessee, Knoxville

Traci L. Haydu

December 2000

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DEDICATION

This dissertation is dedicated to my parents,
Steve and Kathy Haydu, who have always
encouraged and supported me and deserve
endless appreciation.

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Wendell Liemohn for his guidance and encouragement throughout my graduate studies. I would also like to express my sincere appreciation to my other committee members, Dr. Dixie Thompson, Dr. Sky Huck, and Dr. Gene Fitzhugh for their assistance and suggestions. I am grateful and honored to have learned from and worked with the exceptional faculty and staff in the Exercise Science and Sport Management Department. Their dedication and commitment to education and their students have truly made my time at the University of Tennessee rewarding and memorable.

ABSTRACT

Proprioception allows the body to maintain proper orientation during static and dynamic activities. In the upper and lower extremities, research has demonstrated a loss of some aspects of proprioception and improvement in proprioception with retraining. It was hypothesized that persons with low back pain lose some elements of proprioception, although research in this area is relatively new. One aspect of proprioception, repositioning accuracy, was examined in this study.

The primary purpose of this study was to compare repositioning accuracy of individuals with CLBP and healthy controls. Specifically, the ability to reposition the pelvis into a neutral position was examined in standing and seated positions. A secondary purpose of the study was to examine the inter-relationships between low back pain, repositioning accuracy and physical measurements.

The ability to repositioning the pelvis into neutral in both standing and seated positions was tested in 19 volunteers aged 35–55 years old from the University of Tennessee at Knoxville and surrounding community. The participants were divided into two groups based on their Oswestry Low Back Pain Disability Questionnaire score (ODQ). Individuals with an ODQ score of zero were placed in the control group (n = 10). The chronic low back pain group (CLBP; n = 9) included individuals with an ODQ score greater than zero. The groups were similar with regards to age, height, weight, and body mass index. An electronic goniometer (elgon) was used to measure total lumbar range of motion (TROM), baseline neutral position, and neutral repositioning in both standing and seated positions.

Each participant underwent a neutral spine training session following anthropometric, flexibility and strength measurements. Standing TROM was calculated as the sum of extreme anterior tilt and extreme posterior tilt. Following TROM testing, baseline standing neutral spine position was recorded for each individual. The participants then attempted to replicate their standing neutral position. Repositioning error was calculated as the absolute difference between the baseline neutral position and the repositioned neutral position. The same protocol was repeated in an unsupported seated position.

The results of the repeated measures ANOVA demonstrated no significant differences in repositioning accuracy between the CLBP group and the healthy control group in either standing or seated positions. However, there was a significant difference between the standing and seated positions for the sample ($p < 0.05$). Overall, for all subjects, the mean absolute repositioning error was greater in a seated position than in standing. In addition, the groups were no statistically different in TROM or baseline neutral positions in either standing or seated positions. To examine the difference in lumbar lordosis before and after neutral spine training, a single factor (time) repeated measures ANOVA was performed on the measurements obtained with the flexible ruler. There was a significant time effect for both the CLBP and control groups; the lumbar lordosis measures were significantly reduced with neutral spine posture. The between group effect was not significant. MANOVA indicated significant differences between the groups for trunk extension strength and abdominal strength. In both cases the CLBP group had statistically weaker trunk extension and trunk flexion strength.

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CHAPTER ONE

INTRODUCTION

The lumbar spine is vulnerable to injury due to its structure and its role in weight bearing posture. Low back pain (LBP) is common in general and athletic populations, both young and old. It occurs in situations where overload and poor postural control place the spine in vulnerable positions that can result in injury[93]. This is especially true when trunk and extremity flexibility and strength are inadequate to effectively withstand the load, posture or combination of the two.

LBP is a common occurrence, affecting an estimated 80% of people at some point during their lifetime[34]. It has been reported that the annual prevalence of LBP ranges from 15-45%[5]. Deyo[26] reported that in the United States, one-third of the population that reported back pain had symptoms less that one-month whereas another third reported symptoms lasting up to five months. The remaining third reported symptoms lasting longer than six months. The recurrence rates for LBP range from 60-85%[115]. In the United States, LBP is the most common cause of activity limitation in individuals younger than 45 years and the leading cause of disability in individuals over 45 years[6, 88]. Despite considerable research, it has been estimated that chronic low back pain results in 75-100 billion dollars annually in medical health care costs[33].

Chronic low back pain is often considered in the category of general back pain due in part to the lack of a universal definition. Chronic LBP is most commonly

defined as low back pain that persists longer than seven weeks[118]. Others define chronic LBP as pain that lasts longer than the expected period of healing or as frequently occurring back pain, describing its intermittent nature[5].

An integral part of low back pain rehabilitation is stabilization training. Stabilization training is designed to restore muscle function and movement control. Dynamic stabilization, or stabilization during motion, requires adequate flexibility, muscle control and postural positioning[84]. Maintenance of a neutral posture is complex neuromuscular skill requiring continuous fine adjustments in muscle tension in response to fluctuating loads[78]. Proprioception, therefore, is an important key. Proprioception, as defined by Taber's Cyclopedic Medical Dictionary[109] "is the awareness of posture, movement, and changes in equilibrium and the knowledge of position, weight, and resistance of objects in relation to the body." (p. 1608).

In order to acquire the functional components of stabilization training, there must be continuous instantaneous monitoring and feedback from the neuromuscular system. Specifically, the specialized receptors of proprioception (i.e., muscle spindles and Golgi Tendon organs) must be able to provide information on muscle length and tension to the central nervous system to facilitate appropriate motor commands for correct postural adjustments.

Exercises for spinal stabilization are used to attain correct positioning and re-positioning of the spine during static and dynamic activities of daily living (ADL's), including occupational and recreational activities. Neutral spine, also called neutral posture or positioning, is a fundamental component of stabilization training. It is a

biomechanically efficient position of the spine, which minimizes the stress placed on the lumbar spine[2].

There are two essential components required for achieving and maintaining a neutral spine posture. The first component is adequate range of motion (ROM), particularly in the low back and iliofemoral joints to facilitate the needed mobility to obtain the desired neutral position. In addition to ROM, adequate strength is extremely important. Without sufficient muscular co-contraction of the trunk and extremities, the ability to maintain the neutral spine posture (both statically and dynamically) will be compromised[73].

Levine and Whittle[63] demonstrated that pelvic tilt could be actively manipulated in static standing posture. As a result, the tilting can alter the degree of stress placed on the spine[64]. Therefore, neutral spine can be efficiently achieved by controlling the attitude of the pelvis. Pelvic tilt exercises are usually used to decrease the lordosis (sway) of the low back, but may also serve to maintain the lordotic posture in sitting and forward bending. Consequently, proficient coordination of pelvic tilt is a prerequisite for dynamic stability of the spine.

Stabilization programs emphasize neutral spine as a desired position, or position range, or muscle activation and retraining for muscular co-contraction[67]. Clinical observers have noted that patients experienced difficulty in low back repositioning proficiency following low back injury[67]. One of the reasons is that the physiological consequences of common musculoskeletal trauma of the low back appear to have a detrimental effect on lumbar proprioception[87]. Moreover, Parkhurst and Burnett[87]

contend that proprioceptive deficits are associated with increases in low back pain/injuries.

The contribution of proprioception to lumbar muscle function and stability of the lumbar spine received little research focus. Few studies have scientifically investigated proprioception or the effect of injury on proprioception and kinesthetic sense. Although, there have been numerous studies on position sense and reposition of the extremities, particularly the knee and ankle, the application of these concepts to the trunk and low back remains inadequately addressed. In part, this void stems from the lack of a reliable and valid testing instrumentation to assess lumbosacral position sense. If more were known about repositioning/proprioceptive training for individuals with LBP, therapy based on this information could provide further options for the clinician. In addition, the results could demonstrate the importance of proprioception in dynamic stabilization for prevention and rehabilitation programs.

The purpose of the study was to investigate the ability of healthy individuals and individuals CLBP to reposition pelvic posture (proprioception) in standing and seated positions. An electronic goniometer (elgon) was used to record the pelvic position in both standing and seated positions. Secondly, the study examined the relationships between CLBP, proprioception, and other selected variables in both groups of individuals.

Hypothesis

The primary hypothesis was that individuals with chronic low back pain (CLBP) would not be able to reposition their pelvis into a neutral spine position as accurately as healthy individuals in both standing and seated positions. In addition, it was hypothesized that individuals with CLBP would overshoot their neutral position due to proprioceptive deficits. Furthermore, differences in repositioning accuracy would exist between the standing and seated trials. Due to increased proprioceptive input during the seated position, it was believed that the magnitude of repositioning error would be smaller in the seated position in both groups as compared to standing.

CHAPTER TWO

REVIEW OF LITERATURE

The focus of this literature review is to briefly describe the prevalence of low back pain (LBP) as well as explore the history and concepts of low back rehabilitation. The primary emphasis will be on stabilization training including its anatomical foundations (i.e., neutral spine and muscular bracing). Furthermore, research relevant to the neuromuscular foundation of stabilization training will be reviewed.

Prevalence of Low Back Pain

LBP is a common occurrence, affecting an estimated 80% of the population in the United Stated at some point during their lifetime[32]. LBP disables 5.4 million Americans annually; 4 million of those are permanently disabled[57]. More recently, it was reported that the annual prevalence of LBP ranged from 15-45%[5].

Increasing age is associated with an increased incidence of LBP[94]; however, LBP affects people of all ages. In the United States, LBP is the most common cause of activity limitation in individuals younger than 45 years and the leading cause of disability in individuals over 45 years[6, 88].

Most people who experience LBP recover within four to six weeks. Though appearing to be a self-limiting disease process, many cases become chronic, sometimes

leading to permanent disability[6]. Deyo and Tsui[26] reported that in the United States, one-third of the population that reported back pain had symptoms less than one-month, whereas another third reported symptoms lasting up to five months. The remaining third reported symptoms lasting longer than six months. The recurrence rates for LBP range from 60-85%[115]. Despite considerable research, it has been estimated that chronic low back pain (CLBP) results in 75-100 billion dollars annually in medical health care costs[33].

History of Low Back Rehabilitation

The approaches to low back management have dramatically evolved over the past half-century. Initially, the school of thought for the treatment of back pain was bed rest, which perhaps still pervades, but fortunately with diminishing frequency. Inactivity leads to a loss of strength and endurance in the supporting lumbar musculature, promoting dysfunction and making cumulative microtrauma possible[102]. Shiple and DiNubile[102] contend that bed rest has no advantage in most cases and can compromise recovery. The following sections will review the most frequently utilized approaches to low back rehabilitation.

Spinal Flexion Exercises

Flexion exercises were the first structured approach to the rehabilitation of patients with LBP[90]. Williams[121] developed the flexion exercises with the belief that

lumbar lordosis caused damage to the posterior part of the intervertebral disc (IVD) and posterior elements of the spine. In addition, Williams believed that a posterior pelvic tilt was advantageous for pain management when performing activities of daily living (ADLs)[122]. Therefore, flexion exercises may be helpful for patients with osteoarthritis, pars interarticularis defects, spinal stenosis, or when extension is painful in cases of low back sprain or strain[50]. Thus, these flexion exercises were used to encourage a forward pelvic tilt and reduction of lumbar lordosis.

Flexion exercises may not be appropriate for all types of low back conditions. The forward movement associated with this type of exercise increases the compressive stress on the IVD. Therefore, flexion exercises should not be prescribed for individuals with disc pathology[102]. In addition, maintaining a full posterior pelvic tilt makes it difficult and/or awkward to perform many ADLs[92].

Spinal Extension Exercises

Cyriax first advocated extension exercises in the 1960's on the grounds that flexion exercises may exacerbate symptoms of disc pathology[90]. Therefore, extension type exercises were promoted to prevent posterior protrusion of the disc[90]. McKenzie popularized this approach in the early 1980's[27]; however, the approach was entirely based on extension exercises. McKenzie[75] referred to this concept as "centralization, whereby distal symptoms move proximally, toward the midline of the spine or are absent in certain directional movements"[75]. Patient selection is based on a series of test exercises that determine which movements centralize the patient's pain. This theory

was particularly suited for patients with disc pathology or when pain was due to or aggravated by flexion[102]. The patients with this symptomatology were taught to avoid flexed positions to reduce the pressure on the IVD. Extension exercises are effective in decreasing symptoms associated with disc pathologies, but tend to increase the compressive force on the posterior elements (i.e., facet joints and par interarticularis).

Back Schools

Back schools were popularized in the 1970's. These schools were first developed in Sweden and quickly became popular in Canada and the United States[90]. Individuals were taught self-care of back pain through resting positions, use of ice and stretches, and ways to modify movements to avoid placing stress on the spine. Specifically, patients were educated about their condition and instructed in ways of standing, sitting and lifting that reduce strain on the lumbar spine[102]. The techniques taught in the back schools allowed patients to take an active role in their rehabilitation. The back schools provided some good strategies for managing back pain but the body mechanics taught were based on guarded movements of a person with acute LBP[90].

Stabilization

In the 1980's, stabilization training developed as a new school of thought[90, 100]. The underlying principle of stabilization training is based on the functional and structural relationship of the spine and its supporting structures. Specifically, musculature and other connective tissue surrounding the spine (e.g., thoracolumbar

fascia) and iliofemoral joints are used to 'splint' or stabilize the lumbar motion segment. This splinting effect is proposed to minimize excessive movement of the motion segment that accompanies gross movement of the trunk and the body as a whole. Degeneration of the motion segment is believed to be a resultant factor of repetitive and excessive wear and tear.

Stabilization training is an exercise program designed to assist individuals in gaining neuromuscular control of the lumbar spine and pelvis to facilitate coordinated and balanced muscular function[98]. It is further described as a technique that involves abdominal bracing that holds the diseased and painful motion segment (two adjacent vertebrae and the intervening disc) in a pain-free neutral position through voluntary contraction of the surrounding musculature[120].

The goal of stabilization training is to optimize the patient's long-term ability to perform functional activities by reducing the mechanical forces that could result in degeneration through cumulative microtrauma. The degeneration itself is not painful, however, it can result in temporary minor pain (e.g., back strain) but will usually resolve in several days. Eventually, the pain-free degeneration (cumulative trauma) may progress to such a level that the components of the spine are unable to tolerate the forces associated with daily activities and pain may become chronic.

Dynamic lumbar stabilization appears to be an effective approach to restore functional stability of the spine. In a three-year study, patients with herniated discs and radiculopathy were treated non-operatively with an aggressive rehabilitation program, pain management, exercise training to eliminate repetitive trauma, and dynamic lumbar

stabilization. Successful outcomes were demonstrated in 96% of the patients and 92% of the patients were able to return to work[97].

A key component to a stabilization program, including that used in the aforementioned study, is the neutral spine concept. Patients are taught their neutral spine position and then begin stabilization activities to develop strength, endurance and coordination. The muscles surrounding the trunk are used to maintain the neutral posture and to brace the spine. Through muscle bracing forces that would otherwise be transmitted to the spine are absorbed. Furthermore, the ability to detect changes in joint position and the ability to reposition into a corrected neutral posture are critical aspects to the success of the stabilization protocol. Without these attributes, the ability for minimizing movement at a diseased motion segment thereby preventing cumulative microtrauma is reduced.

Comprehension of anatomy as it relates to mechanical LBP is critical to the understanding of the principles and concepts of stabilization training. The following sections will review bony and soft tissue structures as they relate to neutral spine and muscular bracing stabilization concepts.

Anatomical Foundation of Stabilization Training

The lumbar spine is susceptible to injury for a variety of reasons. The spine is the only structural link between the pelvis and the upper body. The lumbar vertebrae support the body weight above the pelvis with the cumulating force being the greatest on the IVD at the lumbosacral junction (L5-S1)[3]. Furthermore, the sacral angle can also

contribute to the weakness of the spine. Normal lumbosacral angle (30-40°) causes vertical compressive forces to act perpendicular and horizontal to the surface causing compression, bending, and shear force[3].

The anatomical design of the vertebral bodies (e.g., high trabecular bone content) and the IVD are such that they are usually capable of withstanding high compressive forces. Kishino, Mayer, Gatchel et al.[55] reported that the exposure to compressive forces of 6000 N and higher puts the spine at a considerable risk of injury compared to compressive loads of 3500 N. The spine, in vivo, may experience compressive forces ranging from 6000 N for everyday tasks up to 18,000 N during competitive power lifting[21]. Shear force places excessive strain on the annulus fibers of the IVD in addition to the neural arch[3]. However, the abdominal muscles, particularly the internal oblique and transversus abdominis, work with the midline ligaments and thoracolumbar fascia (TLF) to reduce shear stress on the motion segment[42].

Mechanical LBP has been viewed primarily as a movement disorder that has either resulted in or has been responsible for low back dysfunction. The spine has a range of optimal positions in which it functions most efficiently. The position varies with physiological status and the stresses it must withstand[41, 78]. However, an individual with low back dysfunction often has limited range of motion (ROM) due to pain. The key in protecting the spine from chronic injury is by minimizing excessive motion (i.e., bending, torsion and shear). Learning to brace the trunk in a pain-free ROM position (neutral spine) may inhibit the diseased motion segment from sending

out pain signals, thereby allowing the individual to resume usual activity[120]. This concept is the underlying foundation of stabilization training.

Neutral Spine

"Neutral spine" or "neutral posture" has been used increasingly in low back rehabilitation. In healthy individuals the neutral spine posture is commonly described as a comfortable position located between anterior and posterior pelvic tilt[100]. In contrast, for symptomatic individuals the concept is more clearly defined as that position between anterior and posterior pelvic tilt that is asymptomatic and comfortable[78, 120].

Neutral spine position or optimal positioning of the pelvis is a primary principal on which stabilization is based[2, 22, 30, 99, 100]. There is no particular lumbar spinal posture that is best for all patients; the neutral spine position must be defined for each individual based on diagnosis and symptoms. For instance, individuals with disc pathology may be inclined to assume a neutral posture that is more extension biased, whereas an individual with a posterior element injury may find a flexed position more favorable.

An important distinction to make is that the neutral spine position does not necessarily mean zero degrees of lordosis[100]. Farwood[30] describes neutral as the position or ROM defined by the patient's symptoms, pathology and musculoskeletal restrictions. This description has also been expanded to include a range of optimal

positions in which the lumbar spine functions most efficiently[96] and tolerates mechanical forces best[30, 78, 100].

As previously mentioned, the abdominal muscular contraction plays an important role in maintaining and stabilizing the neutral position. Individuals can be taught to place their spine in the neutral position and maintain this position through isometric contraction of the muscles surrounding the trunk. This ability, however, requires learning new sensory engrams. It is a complex neuromuscular skill requiring continuous fine adjustments in muscle tension in response to fluctuating loads[78]. Specifically, these adjustments involve controlling the position of the pelvis and the lumbar spine. The following sections will define and discuss the relevance of the angles of pelvic tilt and lumbar lordosis in the neutral spine concept.

Pelvic Tilt

The main function of the pelvis is to transfer the weight of the upper body from the axial to the lower appendicular skeleton. The pelvis also withstands compression and other forces resulting from its support of body weight and its provision of attachments for powerful muscles[1]. It is notwithstanding that the change in orientation of the pelvis may greatly impact these functions.

Pelvic tilt is defined as the angle between the horizontal plane and a line passing through the midpoint of the posterior superior iliac spine (PSIS) and the midpoint of the anterior iliac superior spine (ASIS)[63]. In general, the ASIS and pubic tubercles are

aligned in the vertical plane. The ASIS on both sides are aligned in the horizontal plane[116].

The alignment of the pelvis depends on the interaction between opposing muscle groups. The inability to adequately achieve the needed ROM at the iliofemoral joints may preclude one's ability to obtain a desired pelvic orientation, and therefore the desired neutral spine posture. The hip musculature can be viewed as "guy wires" that support the pelvis. Excessive tightness of the hip flexors, such as the psoas, could increase the forward or anterior tilt of the pelvis[63]. Conversely, hamstring tightness may lead to a posterior pull on the pelvis, thereby creating a posterior pelvic tilt; although this is controversial in the literature[35].

Lumbar Lordosis

Lumbar lordosis is the curve presented by the lumbar spine, which should form a slight anterior curvature[63]. This curvature has a twofold function, namely to increase the flexibility of the spine and add to the overall strength of the spinal column[111]. The key, however, is avoiding extreme lordosis or extreme kyphosis of the lumbar spine[36]. Again, this is where neutral posture(s) come into play.

A small lordotic curve is desirable; the curve assists the IVD with cushioning compressive forces and shock[66]. Moreover, Fairweather and Sidaway[29] contend that individuals with an exaggerated lumbar curvature may be predisposed to LBP. To the contrary, Youdas, et al.[127] demonstrated that individuals with CLBP had no more standing lumbar lordosis or pelvic inclination than healthy controls. It is

notwithstanding, however, that an increased lordotic curve could theoretically lead to an increased load on the posterior elements, leading to possible facet or pars interarticularis pathology[111]. When the pelvis is rotated posteriorly lumbar lordosis decreases, thereby reducing the shear placed on the fifth lumbar vertebrae and sacrum.

Relationship between Pelvic Tilt and Lumbar Lordosis

The relationship between pelvic tilt and lumbar lordosis is influenced by a combination of factors. In postural alignment evaluations, the degree of pelvic tilt influences the degree of lumbar curvature. For example, in relaxed standing, if an individual stood with an exaggerated lumbar lordosis, it would typically suggest that the abdominal muscles are relaxed or weak and therefore elongated. Consequently, the trunk extensors and hip flexors would be in a shortened position. This imbalance would cause an increased anterior tilt of the pelvis and an increased lordotic curve. Imbalances among various factors, such as muscle length and muscular strength, can often lead to LBP.

The abdominal muscles can tilt the pelvis posteriorly and the erector spinae muscles can tilt the pelvis anteriorly[54]. When the pelvis is tilted posteriorly in a standing or seated position, lumbar lordosis decreases[25]. In normal standing, the degree of pelvic tilt is related to the lumbar curvature; however, it may not exclusively be related to the performance and length of the back and abdominal muscles.

Walker, Rothstein, Finucane et al.[119] examined the relationship between lumbar lordosis, pelvic tilt and abdominal strength. Repeated measures of lumbar lordosis (flexible ruler), pelvic tilt (inclinometer) and abdominal strength (double leg lowering)

were performed on 31 healthy individuals. The authors concluded that no relationship existed between lumbar lordosis and pelvic tilt in standing with abdominal strength.

Levine and Whittle[63] examined the relationship between pelvic inclination and lumbar lordosis in standing. These angles were measured in normal standing, maximal anterior tilt, and maximal posterior tilt. In maximal anterior tilt, the pelvic angle changed an average of 11.4° from relaxed standing and increased the lumbar lordosis by an average of 10.8°. Lumbar lordosis decreased by an average of 9.8° when the pelvis was maximally tilted an average of 8.7° posteriorly. Therefore, the authors concluded that altering pelvic tilt significantly changed the angle of lumbar lordosis.

Youdas, Garrett, Harmsen, et al.[128] used multiple linear regression modeling to examine the association between pelvic tilt and lumbar lordosis in standing with eight measured variables in 90 adults. Variables examined included age, sex, body mass index (BMI), physical activity level, back flexibility, one-joint hip flexor muscle length, and abdominal muscle strength and length. There were no regression models that could account for variability in the pelvic tilt or lumbar lordosis in standing.

More recently, Youdas, Garrett, Egan et al.[127] examined the association between the previously mentioned eight variables, plus LBP disability, pelvic tilt, and lumbar lordosis in 60 adults with LBP. In addition, they compared their results to individuals without LBP taken from a previous study[128]. The authors concluded that individuals with LBP had no more standing pelvic tilt or lumbar lordosis than individuals without LBP. However, LBP sufferers demonstrated less abdominal strength on the double-leg lowering test than healthy adults. Again, none of the linear regression models

accounted for much of the variation in the angle of pelvic tilt or magnitude of lumbar lordosis in standing.

Muscular Bracing (Muscular Fusion or Corsetting)

Muscular bracing, also referred to as muscle fusion or corsetting, is a method used to control lumbar lordosis using co-contraction of the trunk musculature. This method decreases the stresses placed on the spine[97]. In muscle fusion the trunk musculature braces the spine and minimizes the movement between the diseased motion segments. This muscular co-contraction in essence forms a corset around the spine and facilitates positioning by keeping the spine in a neutral position.

Repetitive flexion and torsional stress placed on the lumbar IVD and facet joints, particularly at the lumbosacral junction (L5-S1), leads to degenerative changes of this motion segment[99]. Stabilization training is designed to minimize repetitive microtrauma to the diseased lumbar motion segment(s); therefore training can alter the progression of the degenerative process[99, 100].

<u>Internal Oblique and Transversus Abdominis</u>

The abdominal muscles flatten the abdominal wall and compress the abdominal contents. The circumferential arrangement of the transversus abdominis enables this muscle to greatly contribute to the development of intra-abdominal pressure (IAP). It has been suggested that some portion of the internal oblique muscle works with the transversus abdominis in a supporting function. These muscles, with co-activation of the lumbar multifidus (which has been closely linked to spinal segmental support)[91],

provide an important stiffening effect on the lumbar spine that can enhance dynamic stability[7], and also impart tension to the TLF[24, 41]. However, its role may not be as great as Gracovetsky contended[91].

Thus, the transversus abdominis and the internal obliques, along with the lumbar multifidus muscle, are very important in providing dynamic stability to the lumbar spine. However, these muscles often fail at this function in populations with chronic LBP[46, 82, 127]. Studies and clinical tests have shown that transversus abdominis function (i.e., timing of contraction) was poor in patients with LBP[91]. Consequently, O'Sullivan[83] demonstrated that muscle activation/co-activation could be re-trained with specific exercise training of the deep abdominal muscles in patients with chronic LBP.

Thoracolumbar Fascia (Lumbodorsal Fascia)

The thoracolumbar fascia (TLF), also referred to as the lumbodorsal fascia, consists of superficial, intermediate and deep layers. All three layers fuse to form the lateral border the erector spinae; this provides an attachment for the transversus abdominis and a small portion of the internal oblique. Bogduk and Macintosh [12] contend that the intermediate layer of the TLF contributes to the stability in the frontal and sagittal planes and that the posterior layer of the fascia provides support in the sagittal plane. The lateral raphe is formed by the fusion of the middle layer and posterior layers of the TLF at the lateral border of the erector spinae. The lateral raphe junction permits the transversus abdominis (and to a lesser extent the internal oblique) to pull laterally on the TLF and provide a modest anti-flexion moment[12]. The

superficial posterior layer is formed by the aponeurosis of the latissimus dorsi[12] and is continuous with the gluteus maximus and hamstrings, and partly with the external oblique and trapezius[117]. Below the level of the fourth lumbar vertebrae, the fibers cross to the contralateral side and attached to the sacrum, iliac crest, and posterior superior iliac spine (PSIS). Vleeming and colleagues[117] contend that the gluteus maximus and the latissimus dorsi can conduct forces contralaterally through the posterior layer of the TLF. This provides as strong linkage between the trunk and the lower and upper extremities. Therefore the TLF can play an important role in rotation of the trunk and stabilization of the lower lumbar spine, pelvis, and sacroiliac joints[117].

Neuromuscular Foundation of Stabilization Training

Proprioception

The information provided by afferent mechanoreceptors, such as Golgi tendon organs, muscle spindles, and joint receptors allow the body to maintain proper orientation while performing static or dynamic activities[101]. It relates primarily to the position sense of mechanoreceptive sensation[58].

Proprioception is a complex, subconscious interaction between afferent and efferent receptors that allow the body to control the movement and position of the body or a segment of the body[101]. These specialized receptor cells are located in the joints, muscles, ligaments, tendons and skin. They convert mechanical deformation of the tissue into a neural signal, which is then transmitted to the central nervous system that

in turn responds with a signal in an attempt to correct the position[60]. For semantic purposes, it should be noted that proprioception has been synonymously used in the literature with terms such as kinesthetic sense, kinesthesia, position sense, joint sense and deep sensation.

Proprioceptors in the Lumbar Spine

The lumbosacral spine is intrinsically (bony configuration) unstable therefore adequate extrinsic (ligament, capsule and tendon) stability must be present. Extrinsic stability is critical for adapting to abrupt directional changes and fluctuating static and dynamic loads applied to the spine[84]. The location of the key afferent receptors responsible for dynamic joint stability is unclear. Joint capsule, muscle, and ligamentous receptors, however are believed to be important. The articular and muscle receptors are considered to be important in joint stability in that they contribute to joint position sense[101].

Mechanoreceptors have been found in a number of spinal connective tissues, such as lumbar ligaments, facet joint capsules, and IVD. However, the deep musculature such as the multifidus is considered to have the majority of the proprioceptive units[95, 124-126]. Contrary to the cervical spine, where the distribution of mechanoreceptors has been researched extensively, the distribution in the thoracic and lumbar segments is less known[76].

Intervertebral Discs

The IVD is supplied with nocioceptors and proprioceptors in the outermost layers. In addition, the surrounding capsular tissue has been shown to have an abundance of various types of mechanoreceptors and nocioceptors. The IVD creates a distraction force that produces tension within the supporting connective tissues. This preset tension stimulates the stress receptors creating afferent input to the central nervous system; any distortion will increase the central nervous system input creating a variety of reflex motor responses[89].

Ligaments and Facet Joint Capsules

The spinal ligaments and facet joint capsules also have a significant role in providing the central nervous system with information with respect to posture and movement[86]. Although, Amonoo-Kuofi[4] reported segmental distribution of muscle spindles in all muscles of the spine, a less consistent population of encapsulated nerve endings was seen in facet joint capsules in the thoracic and lumbar spine than in the cervical spine. In neutral postures, however, ligaments are under minimal tension and muscle receptors are considered to be the major sensory determinant of position[72].

McLain and Pickar[77] identified Type I and Type II mechanoreceptor endings in thoracic facet joint capsules and Type I, Type II and Type III endings in the facet joint capsules of the lumbar spine. These investigators found Type IV receptors throughout the thoracic and lumbar region. They concluded that encapsulated nerve endings (Type I-Type III) are believed to be primarily mechanosensitive and may provide proprioceptive and protective information to the central nervous system regarding joint

function and position. However, compared to the cervical region, the thoracic and lumbar regions contain a lower population of these receptors[77].

Muscles and Tendons

Muscle spindles, which are more common in postural Type I muscles, are known to have especially high densities in some lumbar muscle groups. Adjacent muscles, particularly the deep muscles (i.e., rotatores) are believed to be responsible for stability and maintenance of posture. In addition to their role of mediating position and movement sense in peripheral joints, muscle spindles are very sensitive to mechanical vibration, suggesting that precise muscle spindle input of the paraspinal muscles is essential for accurate positioning of the pelvis and lumbosacral spine in sitting posture[16].

Proprioception and Low Back Injury

Individuals with LBP may have impairments in certain aspects of proprioception. Yamashita, Cavanaugh, el-Bohy et al.[125] contend that these impairments may persist if proprioception is not specifically addressed in the rehabilitation program.

Proprioceptive deficits have been associated with an increased number of low back injuries[87]; Tropp[113] believed that proprioceptive deficits could impair motor control and lead to functional instability. Proprioceptive feedback plays an important role in conscious and unconscious awareness of joint and limb motion; with respect to the trunk, regardless of the type of activity, the body continuously makes adjustments to

control the center of gravity. In general, proprioception is the ability of the body to detect joint movement and joint position; another important component of proprioception is the ability to acknowledge changes in joint position and reposition the joint accurately. Normal proprioceptive function is essential for injury prevention.

The components of proprioception are believed to diminish in individuals with LBP; however, there is limited research to support the hypothesis. Researchers have attempted to measure proprioception using various techniques such as use of a force platform, electromyography and measures of position sense[80, 105, 123]. Proprioception is complex and difficult to measure; this contributes to the limited research on the contribution of proprioception to lumbar muscle function and stability of the lumbar spine. Furthermore, few studies have scientifically investigated proprioception or the effect of injury on proprioception and kinesthetic sense.

Gill and Callahan[38] found significant differences in proprioception between individuals with LBP and those free from LBP. Taimela, Kankaanpaa and Luoto[107] demonstrated that lumbar fatigue impairs the ability to sense a change in lumbar position. Furthermore, patients with LBP had less ability to sense a change in lumbar position than controls even when they were not fatigued[107]. Swinkles and Dolan[106] demonstrated that repositioning accuracy in healthy individuals did not change with incremental increases in the range of motion, suggesting that spinal position sense is independent of the magnitude of movement.

Measurement of Proprioception

Position sense and repositioning accuracy are commonly used to indirectly measure proprioception[14, 58]. These two measurements will be defined and discussed in the following sections.

Position Sense

Position sense is the ability to recognize the orientation of movement of a body segment in space[79]. Joint position sense is typically measured using passive threshold to detection. For example, a joint is passively moved at a slow rate of constant motion and the subject signals in response to questions about change in the joint position[9]. Thus it can be a measure of the smallest motion an individual can perceive in a given plane and direction of motion[87].

Repositioning Accuracy

Repositioning accuracy is the ability to reproduce the orientation of a body segment in space[79]. This method is used to test the ability to reproduce the position in which a joint has been previously placed. Many times the body segment is passively placed at a specific joint angle then returned to a starting position. The individual is then asked to return the body segment to the target position. Repositioning accuracy is typically reported with regards to error, measured in absolute terms.

Research Relevant to Position Sense and Reposition Accuracy

There have been numerous studies on position sense and reposition of the extremities, particularly the knee and ankle. However, the application of these concepts to the trunk and low back remains inadequately addressed. Moreover, evidence regarding the effects of rehabilitation on proprioception has yet to be verified in peripheral joints or in the low back[56, 61]. In the following sections a review of the literature will be made in both the extremities and the low back.

Extremity Proprioception Research

Glencross and Thornton[39] found a linear trend between the degree of position sense error and the range of movement in three groups of subjects with varying degrees of ankle injuries. The largest error occurred in the largest range of movement compared to the uninjured ankle and controls. In addition, the greatest degree of error was found in the most severely injured ankles.

Garn and Newton[37] measured kinesthetic awareness using a passive movement detection protocol. The authors found kinesthetic deficits and injured ankles of athletes with a history of multiple ankle sprains. In addition, athletes demonstrated increased postural sway in the involved joint during one-legged balancing tasks. Goldie, Evans and Bach[40] found that postural deficits in subjects that had sustained an ankle injury, but did not receive proprioceptive training, were higher in number than those who participated in proprioceptive training.

Diminished proprioception has been documented after ACL rupture[23] and following ACL reconstruction[10]. Barrack et al.[8] demonstrated an increase in the threshold to detection of passive movement in the majority of individuals with ACL rupture and functional instability. Corrigan et al.[23] measured proprioception in the knees of 20 subjects with instability of the anterior cruciate ligament and compared with 17 age-matched control subjects. They found a diminished position sense and threshold for movement detection in the injured patients compared with the control group.

It is believed that some degree of proprioceptive deficit can be improved with retraining. Tropp, Odenrick, and Gillquist[114] found that proprioception training on a balance-rocker had a significant effect for decreasing postural deficits. In another study from the same lab it was demonstrated that a lower rate of injury occurred in soccer players who underwent proprioceptive training compared to controls who had not had proprioceptive training[112].

Similar to the ankle, proprioceptive training has been shown to reduce the incidence of knee injuries as well as to improve rehabilitation after ACL injuries[20]. These investigators studied the possible preventive effect of gradually increasing proprioceptive training program in soccer players (i.e., 300 controls and 300 experimental). Both subject groups were observed for three whole soccer seasons for possible ACL injuries. They found an incidence of 1.15 ACL injuries per team per year in the control group and 0.15 injuries per team per year in the proprioceptively trained group. Lephart, Pincivero, and Rozzi[62] showed that proprioceptive acuity following

knee joint ligament reconstruction and proprioceptive training could be improved in a comprehensive rehabilitation program.

Trunk Proprioception Research

Very little research has been done on proprioception in the trunk, this in part is due to difficulty in controlling extraneous movements at specific spinal levels. In several studies proprioception and motor control in the lumbar spine have been examined by a variety of methods, including electromyography, postural sway, position sense and reposition accuracy.

Electromyography has been used to study proprioception by measuring patterns of trunk muscle activity and monitoring muscle groups simultaneously. Granata and Marras[43] demonstrated that muscle recruitment is optimized by the central nervous system, depending on the task to be performed. Recruitment patterns of the erector spinae muscles during sagittal movements have revealed greater variability in individuals and between individuals[68, 69]. Paquet, Malouin, Richards et al.[85] found an altered pattern of muscle activation in individuals who experienced LBP when performing a sagittal flexion movement.

Proprioception has also been examined through postural sway measurements. Byl and Sinnott[18] compared postural sway under a variety of stable and unstable conditions of a group of individuals with LBP and a control group. The results demonstrated that the group with LBP had greater postural sway, having an increased difficulty with righting and postural reactions. However, the authors could not conclude that the difficulty was due entirely to the LBP. Nies et al.[80] compared postural

sway in subjects with and without back pain. The results of the force plate analysis also revealed that individuals with LBP demonstrated significantly greater postural sway than individuals without LBP. Moreover, they were also less likely to maintain balance on one foot than subjects without pain.

Position sense may not be as sensitive as postural sway as a measure of proprioception for individuals with LBP because some feedback stimulus may result from the pain itself[58]. Nevertheless, proprioception has been examined in this way in a few studies. In healthy individuals, research studies suggest that minimal error occurs in position sense and repositioning accuracy of the trunk and low back[49, 74, 106, 108]. However, position sense and repositioning accuracy have been shown to be impaired as a result of injury or pathology to the low back[38, 87].

Maffey-Ward et al.[67] studied repositioning error of the lumbar spine in healthy subjects as they returned to neutral from a flexed position while seated. Repositioning error was found to be 2.6°, with no significant difference between two testing days.

Gill and Callahan[38] measured lumbar proprioception in individuals with and without LBP. Participants were asked to reproduce pre-determined target positions in standing. Repositioning accuracy was measured and visual feedback from a computer screen was provided to the participants to learn their pre-determined position. The participants were placed at 20° of trunk flexion. The LBP group demonstrated a significantly higher repositioning error than the control group. The authors concluded that further research was needed to determine an effective protocol for identifying proprioceptive deficits.

Lam, Jull and Treleaven[56] studied the ability of 20 subjects with LBP to return to an upright neutral position following movement into full lumbar flexion using the protocol previously described by Maffey-Ward et al.[67]. Trunk repositioning was measured using a non-invasive electromagnetic tracking device (3 Space Fastrack System) on two separate days. Individuals were placed in a seated position and then required to return to an upright position following full lumbar flexion. The mean absolute repositioning error was 2.25° on day one and 1.62° on day two. In addition, the results indicated that their subjects overshot the upright position in 79% of the trials and undershot it in 19%. Subjects were able to reproduce exactly the original starting position in only 2% of the trials. It was suggested that patients with LBP may attempt to use extra mechanoreceptive cues to compensate for deficits.

Newcomer, Laskowski, Yu et al.[79] compared trunk repositioning performance in individuals with and without CLBP using a protocol similar to that of Maffey-Ward et al.[67]. Individuals were asked to reposition the trunk in flexion, extension, and lateral bending. The results indicated significant differences in accuracy due to the direction of movement. CLBP and controls did not differ significantly with regards to repositioning accuracy.

Impaired proprioception in individuals with LBP may persist if not specifically address through rehabilitation, for these individuals may have an alteration in afferent feedback which can lead to poor control of posture and movement[17]. This may lead to the development of compensatory or substitution patterns as well as poor body mechanics. Poor postural alignment may increase the force that is directed to the spinal

structures. As a result, an increase in stress and loading may occur on the structural components of the spine.

Many current rehabilitation programs are designed to improve proprioception under the assumption that proprioceptive deficits occur as a result of LBP[17, 51, 99]. Conversely, lack of proprioception is believed to cause LBP. In either case, there is a lack of conclusive evidence that supports either assumption. Despite the absence of definitive knowledge of specific aspects of proprioception, rehabilitation programs can be designed to challenge, enhance, and improve the system. Specific proprioceptive training may help to fine tune the afferent-efferent arcs[58].

Summary

The lumbar spine is vulnerable to injury due to its structure and its role in weight bearing posture. Dynamic lumbar stabilization appears to be an effective approach to restore functional stability of the spine. Stabilization training and the neutral spine position are used to reduce the cumulative microtrauma of daily activities. However, maintenance of a neutral posture is a complex neuromuscular skill that requires continuous fine adjustments in muscle tension. Stabilization programs emphasize neutral spine as a desired position and muscle co-contraction to stabilize the position. However, clinical observations have noted that patients experience difficulty in low back re-positioning proficiency following low back injury. The physiological consequences of musculoskeletal trauma of the low back appear to have a detrimental effect on lumbar proprioception. If more were known about repositioning/

proprioceptive training for individuals with LBP, therapy options for the clinician could be based on this knowledge. The results could also demonstrate the importance of proprioception in dynamic stabilization for prevention and rehabilitation programs.

CHAPTER THREE

METHODS AND PROCEDURES

The purpose of the study was to investigate the ability of healthy individuals and individuals with chronic low back pain (CLBP) to reposition pelvic posture in standing and seated positions. An electronic goniometer (elgon) was used to record pelvic postures. The inter-relationships between CLBP, proprioception, and other selected variables were also examined in the study. The primary focus was placed on the differences of reposition accuracy between the healthy individuals and individual with CLBP.

Subjects

Nineteen individuals (9 CLBP and 10 controls) between the ages of 35-55 years old volunteered to participate in the study. Since the average onset of LBP occurs at approximately the age of 45, this age group was chosen to capture those individuals that have most likely experienced CLBP as well as those who may not have experienced LBP. Volunteers were recruited from the University of Tennessee, Knoxville campus and surrounding community. To qualify as potential subjects, individuals had to have either (a) no history of LBP (controls) or (b) a history of CLBP. Chronic low back pain (LBP) in this study was defined as back pain that persists for at least three months or frequently re-occurring back pain. All individuals were screened, to control for

confounding variables described in the next section, prior to being accepted into the study. Proceeding all testing, the experimental protocol was explained in verbal and written form. All participants agreed to volunteer in the study and completed an informed consent statement approved by the Institutional Review Board of the University of Tennessee (Appendix A). To ensure consistency, the primary investigator conducted all testing using a standardized protocol.

Participants were asked to complete an information/medical history form (Appendix B) and Oswestry Low Back Pain Disability Questionnaire (ODQ)[28] (Appendix C). Participants were given the opportunity to ask questions before, during and after testing. Subject inclusion criteria for this study are outlined in Table 3.1.

Participants were placed in one of two groups based on the absence or history of CLBP. Controls reported no history of CLBP and had an ODQ score of zero. Individuals with CLBP reported a history of CLBP within the last five years and had an ODQ score greater than zero.

Table 3.1. Subject Inclusion Criteria

CRITERIA
Age ≥ 35 or ≤ 55
No acute inner ear infection
No history of vestibular disorders
No history of lower extremity pathology or back surgery
No balance, coordination or stabilization training within the last 6 months
No significant health risk factors that may effect balance/proprioception (e.g, diabetes)

Confounding Variables

Kinesthetic sense determines the position and movement of limbs without visual feedback. Kinesthesia can be positively and negatively impacted by many factors. Therefore, several variables were controlled in this investigation that could affect the results of the study.

Visual, vestibular and somatosensory input has been shown to enhance kinesthetic sense. Visual input provides spatial cues that assist the body to determine position and movement of the trunk and limbs. In the current study, participants were tested with their eyes open. An objective of the study was to replicate clinical instruction and functional activity. In a clinical setting, individuals are taught to find their neutral spine with their eyes open. Recently, Newcomer et al.[79] demonstrated no significant differences in repositioning accuracy between visual and non-visual conditions in patients with CLBP or controls.

Vestibular input has been shown to increase an individual's ability to reposition the trunk in standing position[49]. Vestibular information assists the body in maintaining and upright position against the force of gravity. To control for head movement, participants were instructed to "look straight ahead and focus on the mark on the wall."

Proprioceptive input is also obtained from the mechanoreceptors in joints, muscles, ligaments, tendons and skin. Participants were asked not to drink or eat for two hours prior to testing to eliminate the possibility of a distended stomach that could result in mechanoreceptor feedback from the abdominal region. Participants wore

shorts and tank tops to eliminate cutaneous sensory input from relative movement between the skin and clothing.

Age, muscle fatigue, and pain have been found to negatively affect kinesthetic sense. Kaplan, Nixon, Reitz et al.[52] demonstrated that increased age decreased kinesthetic awareness. In their study, the younger age group (under 30 years) had a higher ability to reproduce joint angles of the lower extremities than the older age group (over 60 years). The average absolute differences were four and seven degrees, respectively. The age of the participants in the present study ranged from 35 to 55 years old to control the aging effects on proprioception. The groups were similar in age to ensure comparable mean ages in both groups.

Muscle fatigue has been found to affect an individual's ability to reproduce joint angles in the lower extremity[107]. To prevent fatigue, participants were asked to refrain from participation in any strenuous physical activity for 24-hours prior to testing.

Pain or nocioceptive input has been shown to confound kinesthetic awareness. Subjects in the current study were screened for acute pain in conjunction with activity. Participants were asked to if they had recently experienced pain with full lumbar flexion either standing or seated positions. In the event that the activity caused acute pain, subjects were excluded from the study to ensure the kinesthetic measure was not confounded by any pain avoidance strategy[67].

Instrumentation and Methodology

Low back pain information was gathered using The Oswestry Low Back Pain Disability Questionnaire (Appendix C)[28]. The anthropometric data were collected with a calibrated height and weight scale, meter stick, cloth measuring tape, calibrated flexible ruler and skinfold calipers. The flexibility measures were collected with fluid-filled inclinometers and universal hand-held goniometers. Strength measurements were taken using manual muscle testing protocols. The pelvic positions were collected using a flexible electronic goniometer.

The Oswestry Low Back Pain Disability Questionnaire

Low back pain was assessed with the Oswestry Low Back Pain Questionnaire (ODQ)[28], which indicates the disability level of subjects with CLBP. In this study, the ODQ was used to classify individuals into control and CLBP groups and for the purpose of comparing the results with other studies. Participants completed the self-report that resulted in an index of the individual's perceived disability based on 10 sections that refer to ADLs that might be disrupted by CLBP. Each section contains six statements that describe a greater degree of difficulty in that activity. The individual marks the statement that best describes his/her limitations most accurately. Each section is scored on a six-point scale (0-5), with five representing the greatest disability. The scores of the sections are added together then divided by the maximum score of 50. The score is multiplied by 100 and expressed as a percentage.

The questionnaire has been shown to be valid and reliable[28,44]. Fairbank, et al.[28] demonstrated a near linear decrease in mean ODQ score in a group of 25 patients with acute LBP over a three-week period. The results suggested the ODQ produced reliable estimates of LBP disability. Furthermore, 22 patients with CLBP completed the ODQ at the same time on two consecutive days. Pearson product moment correlation coefficient demonstrated significant test-retest reliability ($r = 0.99$) in this group of individuals[28]. Gronblad, Hupli, Wennerstrand et al.[44] examined the reliability for the ODQ in 20 individuals with CLBP. These CLBP sufferers completed the ODQ on two separate occasions, one week apart. The test-retest reliability of the assessments was estimated by intraclass correlation coefficient ($ICC = 0.83$). The findings suggest that the ODQ produced valid and reliable measurements for predicting disability due to LBP.

Anthropometric Measurements

Height and Weight

Height was measured to the nearest centimeter (cm), with the participant standing in socks with their feet together and heels close to the wall. The measurement was taken with a standard meter stick. Weight was measured with a standard calibrated scale and recorded to the nearest one-quarter pound then converted to kilograms (kg).

Body Mass Index (BMI)

Body mass index was defined as the ratio of weight (in kilograms) divided by height (in meters) squared. In the literature, BMI appears to be the most commonly used body weight/height index when attempting to explain the association between body weight and LBP[59]. However, it must be noted that BMI fails to consider lean body mass; it is possible that the BMI value will be overestimated for a healthy, muscular individual.

Skinfold Thickness

Body composition was estimated by measuring skinfold thickness for each participant using calipers (Lange; Cambridge Scientific Industries, Cambridge, MD). Because gender influences areas in which fat is stored, separate skinfold equations for males and females were used. The sum of three sites (chest, abdomen, and thigh) were used for males along with the Jackson and Pollock[47] equation. The sum of three sites (tricep, suprailiac and thigh) and the Jackson, Pollock and Ward[48] equation was used for females. The sums of the skinfolds were used to estimate the percentage of body fat for men and women from published tables.

Torso Length

Torso length was measured to the nearest centimeter using a standard cloth measuring tape. Measurements were taken with the participant in an erect standing position. Torso length was defined as the distance between the spinous processes of the seventh cervical (C7) vertebra and second sacral (S2) vertebra.

Lumbar Curvature

Lumbar lordosis was measured using a 45-cm calibrated flexible ruler (Flex-a-shape Designing Curve, W.H. Collins, Inc., Whippany, New Jersey), according the procedure described by Youdas, Suman and Garrett[129]. The technique was used to estimate lumbar sagittal curve in relaxed standing and standing in a neutral position by measuring the midline contour of the back. The flexible curve measurement has been reported to be a reliable and valid measure of lumbar lordosis[45]. Measurement of lumbar lordosis using the flexible ruler has been shown to be simple, accurate and reproducible, particularly when taken by the same investigator (ICC values of .73-.94)[65]. In addition, a high correlation between the flexible ruler and radiographs has been demonstrated in previous research[45, 110].

Participants stood barefoot, in a relaxed position with weight evenly distributed shoulder width apart, with arms at the sides. The foot placement was outlined to reproduce the standing position to facilitate consistency while the measurement was repeated in a neutral position following neutral spine instruction. The measurement was taken with the participant's trunk touching against a horizontal cross bar, positioned approximately chest high, to control postural sway during the measurement.

Once positioned, vertebral landmarks were identified and marked with small adhesive stickers. The spinous processes of the twelfth thoracic (T12) and second sacral (S2) vertebrae were identified with the adhesive markers with a line drawn through the center of each marker. The spinous process of T12 was located by identifying the inferior margin of the twelfth rib bilaterally. The margins of the ribs were palpated simultaneously while moving superiorly and medially with each thumb

until they disappeared deep into the soft tissue. The location of the spinous process of T12 was estimated by bisecting a straight line joining the tip of each thumb. The spinous process of S2 was estimated by bisecting a line between the posterior superior iliac spines (PSISs).

The flexible ruler was placed along the midline of the lumbosacral spine and fitted to the contour of the lumbar curve. The points in the flexible ruler were marked at the point where they intersected the horizontal line on the adhesive markers. These points represented the location of the spinous processes for T12 and S2. The flexible ruler was removed without changing its shape, and the convex side was traced onto paper, including the location of T12 and S2. The points of the tracing between T12 and S2 were connected as a straight line (L). A compass was adjusted so the distance between the arms was greater than half the length of L. The fixed arm of the compass was positioned at the point marking the spinous process of T12 and a small arc was drawn on both the convex and concave sides of the tracing. The procedure was repeated, with the fixed arm of the compass at the point designating the S2 spinous process. The centers of the two arcs were connected by a straight line (H), which bisected the vertical line (L). The length of H and L (cm) were used to calculate the index of lordosis, labeled as theta (θ) using the following formula[45, 110, 129]:

$$\theta = 4 \times [\arctan(2H / L)]$$

Flexibility

Flexibility tests of the trunk and lower extremities were performed for each subject prior to the neutral spine repositioning tasks. Specifically, lumbar spine flexion

and extension was measured using the double inclinometer method[53]. Hamstring length was assessed using the passive straight leg raise measured with an inclinometer[53]. Hip flexor length was evaluated using a universal hand-held goniometer and the one-joint Thomas test[54].

Trunk Flexion-Extension

The double inclinometer technique (DI) described by Keeley and colleagues[53] was used to evaluate sagittal lumbar ROM. The double inclinometer method has been shown to be accurate and reliable in previous studies[53, 70]. This technique is not influenced by the height of the subject, thus improving the accuracy of the inter-subject comparisons.

Inclinometers were placed perpendicular to the joint space at the thoracic and sacral levels to measure trunk flexion and extension. One inclinometer was placed at the interspace at level of the T12-L1 interspace to represent gross lumbar motion. The second inclinometer was placed over S2 to represent hip joint motion. The skin was marked with ink just above each inclinometer to ensure proper placement for each measurement. Trunk flexion and extension measurements were repeated three times. The average sacral score was subtracted from the average thoracic score for both flexion and extension. The sacral and thoracic scores were added to determine true lumbar range of motion.

The participants stood with arms relaxed to their sides and were asked to flex forward fully with the knees straight and then to return to the upright position. The

participant was then asked to place their hands on their hips, keep knees straight and arch backwards as far as possible. The numbers from each inclinometer were recorded for flexion and extension[53, 71].

Hamstring Length

Hamstring length was measured using the passive straight leg raise (SLR) with a single inclinometer[53]. Participants were placed supine on an examination table. The inclinometer was placed approximately 2 cm below the tibial tuberosity. The participant was instructed to flatten the low back by pressing it into the table-top and maintain that position while the measurement was taken. The investigator passively raised the straight leg to a point where the opposite thigh was just beginning to lift off the table. Three measures of hamstring length were obtained for each leg. The average of the measures represented the final hamstring length for each leg.

Hip Flexor Length

Hip flexor length was assessed using the one-joint Thomas test described by Kendall and McCreary[54]. The one-joint Thomas test measures the ability of the hip flexors to be lengthened, specifically the iliopsoas muscle. Normal one-joint hip flexor length is represented when the low back and sacrum are flat on the table and the calf touches the table when the knee joint is in full extension.

Participants were placed supine on the examination table with hips and knees straight and their arms folded across their chest. The left lower leg was passively moved towards the chest of the participant, producing hip and knee flexion. The lower

leg was moved until the participant's low back was flat against the table as determined by palpation. The right trunk angle was measured with a universal hand-held goniometer similar to the technique described by Youdas et al.[128]. The test was repeated on the opposite side following the same procedure. Three measures were obtained for each leg with the final hip flexor length representing the average of the right and left legs.

Strength Testing

Trunk extensor, hip flexor, and hip extensor strength was assesses using manual muscle testing (MMT) described by Kendall and McCreary[54]. MMT was scored on a 0-5 scale with 5 representing normal strength. The principal investigator was clinically trained in the MMT procedure. Trunk flexion strength was assessed using the double leg lowering technique described by Kendall and McCreary[54] and modified by Walker et al.[119], and Youdas et al.[128]

Trunk Extensor Strength

Trunk extensor strength was assessed using the active extension technique described by Kendall and McCreary[54]. The participant was placed in a prone position on the examination table. The initial starting position was prone with hands clasped behind the neck. The lower extremities were stabilized on the table by the investigator. The participant was asked to raise the head, shoulders, and chest off the table as far as

possible. The investigator applied resistance to the upper back between the scapulas, attempting to push the trunk down towards the table.

Lower Extremity Strength

Manual muscle strength testing for the lower extremity as described by Kendall and McCreary[54] was performed bilaterally for the hip flexor, hip extensor, and knee extensor muscle groups. The same investigator performed all manual muscle tests to ensure consistency of the resistance given to each participant.

Hip Flexors

The hip flexors were tested as a group. The participant sat with both legs over the edge of the table. The leg was positioned in hip flexion with the knee flexed; the thigh was a few inches from the table. The position was held while the investigator applied pressure against the thigh in the direction of hip extension.

Hip Extensors

The participant was placed in a prone position on the table. The participant was asked to lift the leg off the table keeping the knee straight, maintaining that position as the investigator applied resistance to the leg, attempting to push the leg back down towards the table.

Trunk Flexion Strength

Abdominal muscle strength was assessed using the double-leg lowering method originally described by Kendall and McCreary[54] and modified by Walker et al.[119], and Youdas et al.[128]. The double leg lowering technique has been previously reported as reliable[119] and the preferred clinical test for determining trunk flexor strength[104].

Two investigators were required for the completion of this test. The participant was positioned supine on the examination table with arms folded across the chest and the knees flexed. The primary investigator assisted the subject in raising the legs to the initial position. The participant was instructed to lower both legs towards the table over a 10-second period, keeping the lower back pressed against the table. The primary investigator counted aloud as the subject lowered the legs to the final count of "one-thousand ten"[128].

The abdominal strength score was the angle formed between the long axis of the leg with the horizontal plane. The measurement was obtained the instant the lumbar spine came off the table. A score of zero was recorded if the individual was able to maintain a flat back throughout the range until the heels met the table surface.

The abdominal strength test was performed three times with a one-minute rest period between measurements. Abdominal strength scores can vary from 90 to 0 degrees depending the on the strength of the abdominal musculature. A smaller angle indicated better muscle strength since the abdominals hold the low back flat against the table throughout a greater range of double-leg lowering.

Pelvic Postures

Measurement of pelvic postures was obtained using an elgon (BIOPAC Systems-TSD130B). The elgon was connected to an amplifier (BIOPAC Systems-UIM100A) and connected to a personal computer via an A/D converter (National Instruments). Data were sampled at a rate of 200Hz for a period of 10 seconds. The signal was amplified at 5000 Hz. Prior to the data collection the elgon was calibrated against standard goniometric measurements (ICC = 0.97).

Boocock, Jackson, Burton et al.[13] compared a modified electrogonoimeter (elgon) with inclinometer measurements in flexion and extension for accuracy and reliability. Furthermore they continuously monitored lumbar curvature in for a period of two hours in four mechanics for reliability and feasibility. The results demonstrated that measurements for sagittal mobility were comparable to those derived using an inclinometer and flexicurve[13].

Brumagne, Lysens and Spaepen[15] examined the accuracy of a piezoresistive elgon in measuring lumbosacral repositioning in healthy subjects. A piezoresistive elgon and a 3-D video analysis system were used to measure the repositioning accuracy of pelvic tilting in standing in 11 healthy subjects. Overall mean repositioning accuracy was 1.87°. Repeated measures analysis of variance revealed no significant mean absolute differences between sessions. Correlation coefficients between elgon and 3-D video measurements of position sense ranged from 0.84 to 0.97. The authors concluded that the instrument was adequate for measuring lumbosacral repositioning accuracy. In addition, it was concluded that healthy individuals were capable of repositioning their pelvis and back precisely.

Extreme Anterior and Posterior Pelvic Tilt

Participants were asked to position their pelvis into extreme anterior and posterior pelvic tilt. Individuals were advised to tilt until resistance was felt without causing pain or discomfort. Measurements (in degrees) were taken in both standing and seated positions and measured by the elgon.

Total Range of Motion (TROM)

The difference between anterior pelvic tilt and posterior pelvic tilt was considered the total range of motion of the pelvis. Neutral spine posture fell within this range of motion.

Neutral Spine Posture

Neutral spine posture was defined as that position located between extreme anterior and posterior pelvic tilt, which was comfortable, in healthy participants[2, 100]. Neutral spine posture in unhealthy subjects was defined as that position between anterior and posterior pelvic tilt that was asymptomatic and comfortable[78, 120]. Baseline measurements of neutral posture were measured with the elgon in both seated and standing positions. These positions were used as the criterion position for repositioning accuracy.

Criterion position was the individual's neutral spine posture measured at baseline. Reposition accuracy was measured in seated and standing positions. Individuals were asked to reproduce their neutral position in unsupported sitting and in standing positions.

Proprioception was measured by the ability of the participant to reposition the pelvis into a neutral position (reposition accuracy). Reposition accuracy was measured as a mean absolute error (the difference between criterion position and matching position). Criterion position was designated as the individual's neutral spine posture measured at baseline. Reposition accuracy was measured in seated and standing positions. Individuals were asked to reproduce their neutral position in unsupported sitting and in standing position. The physiological consequences of common musculoskeletal trauma of the low back appear to have a potentially detrimental effect on lumbar proprioception[87]. It has been shown that the degree of pelvic tilt can alter the degree of stress placed on the spine[64]. The inability to reposition or maintain posture in a neutral position can result in increased force on the low back resulting in repetitive microtrauma.

Physical Activity Status

The physical activity status was obtained by self-report on the subject information sheet. Individuals were asked to estimate their weekly activity level in minutes. Weekly activity included work and leisure time activity.

Testing Protocol

The testing procedure consisted of a single session lasting approximately 60-75 minutes. All data were collected in the Biomechanics/Sports Medicine Lab at the University of Tennessee at Knoxville. The testing session involved the collection of

anthropometric and biomechanical data, that included measures of height and body weight, flexibility of the low back and lower extremities, strength of the low back and lower extremity, body composition with skinfold calipers, and lumbosacral/pelvic tilt position with the elgon. The testing session is outlined in Table 3.2.

Table 3.2 Protocol for the Testing Session

ORDER	DESCRIPTION
Forms	Informed consent, info/med hx & ODQ
Anthropometrics	Height, weight, torso length and body composition
Flexible Ruler	Lumbar curve measure in normal relaxed standing
Warm-up	Stationary bike and static stretching
Flexibility	Hamstring, hip flexor and trunk
Strength	Abdominal, low back and lower extremities
Neutral Spine (NS)	Instruction, demonstration and practice
Flexible Ruler	Lumbar curve measure in neutral spine standing
Elgon Preparation	Elgon placement
Pelvic Postures - Standing	Find extreme anterior and posterior range of motion
Baseline NS - Standing	Find baseline neutral spine in standing position
Repositioning - Standing	Reposition in standing posture
Pelvic Postures - Sitting	Find extreme anterior and posterior range of motion
Baseline NS - Sitting	Repeat baseline neutral spine in seated position
Repositioning - Sitting	Reposition in seated position

Anthopometric Measurements

Measurements of height, weight, torso length, skinfold thickness and lumbar lordosis curvature were obtained on all subjects as previously described in the instrumentation section following the completion of the informed consent, information/medical history forms and ODQ.

Warm-up

Each participant performed a standard warm-up and stretching protocol consisting of five minutes of light cardiovascular activity on a stationary cycle ergometer followed by five minutes of static stretching. Participants wore a watch (Polar, Inc) to monitor their heart rate during the warm-up. Participants were instructed to keep their heart rate below 50% of their age predicted maximal heart rate. Age predicted heart rate was determined by subtracting the age of the participant from 220.

Flexibility and Strength

Each participant underwent a series of flexibility and strength measurements described in the preceding sections. Trunk range of motion was measured in a standing position for trunk flexion and trunk extension. Hamstring length and hip flexion was measured bilaterally with the participant in a supine position. Manual muscle strength tests were performed on the abdominal, trunk extensor, hip flexor and extensors muscle groups as described by Kendall and McCreary[54].

Neutral Spine Instruction/Training

A brief description of the neutral spine concept and history of dynamic stabilization concept was provided to each participant. The examiner demonstrated pelvic tilt and neutral spine in a supine and upright position. Neutral spine position in the supine position was described as a "clock dial". Pelvic tilting occurred at the "12 o'clock and 6 o'clock" positions representing posterior and anterior tilt. Neutral spine

position in the standing position was described and demonstrated as the "hip dial" analogy proposed by the San Francisco Spine Institute[100].

Participants began in a supine position on the examination table and were instructed to tilt their pelvis to "12 o'clock and 6 o'clock". Participants progressed into a seated then standing position and tilted the pelvis through a full range of motion. Once participants were comfortable with pelvic tilting they located their neutral spine position in both the seated and standing postures. In both seated and standing positions participants were instructed to maintain their neutral position by contracting their abdominal, gluteal and low back musculature.

Following the neutral spine instruction, participants repeated the flexible ruler measurement. Participants stood in their neutral spine position, resting lightly against the horizontal bar, while the flexible rule was placed along the midline of the lumbosacral curve. The flexible ruler was removed and the convex side traced onto paper, as previously described.

Elgon Testing Procedure

At the beginning of testing, the participants were instructed to move slowly and they were reminded throughout testing to slow their movements if the investigator thought they were moving too quickly. The testing order for each condition, standing and seated, was as follows: (1) maximum range of motion (2) neutral baseline and (3) repositioning to neutral. When finding maximum range of motion, participants were instructed to move slowly in the posterior direction, then anterior direction, and then return their normal position. In standing and seated neutral positions, the investigator

attempted to regulate each participant's movement so that it took five seconds to move to the desired position and five seconds to hold the neutral position.

Neutral Spine – Standing

Elgon Prep and Placement

Participants stood barefoot, in a relaxed position with weight evenly distributed shoulder-width apart, with arms at the sides. The foot placement was outlined on the floor with chalk. The elgon was placed along the midline of the lumbosacral spine. The elgon sensors were secured with double-sided tape over the spinous processes of T10 and S2.

Extreme Anterior and Posterior Pelvic Tilt - Standing

Participants were instructed to stand with their arms at the sides and to tilt their pelvis into extreme posterior and anterior pelvic tilt to determine total range of motion (TROM). The examiner prompted them to "rotate the hip dial backwards to flatten the back" then "rotate the hip dial forward" as far as they could without feeling any pain. Participants then returned to their normal relaxed standing position. The extreme ranges of motion were collected in a single trial lasting 10-seconds, where the speed of the participant's motion was controlled via verbal commands by the investigator. The condition was repeated three times, with approximately one-minute between each trial.

Baseline Neutral Measurement - Standing

Following TROM measurements, the baseline neutral spine measurement was obtained. Baseline was established as an average of three separate 10-second repetitions. Each repetition consisted of posterior to anterior pelvic positioning followed by obtaining the individualized neutral spine position as previously defined in the Instrumentation and Methodology section. Once neutral was obtained, individuals were instructed to hold that position for the remaining time of the trial. The speed of the participant's motion was controlled via verbal commands by the investigator. There was approximately one-minute between trials in which participants were instructed to stand in a relaxed position shifting the body weight from side to side. The calculated average of the three repetitions then served as the reference criterion upon which all subsequent standing trials were compared.

Repositioning Accuracy - Standing

Proprioception was measured by the ability of the participant to reposition the pelvis into a neutral position (reposition accuracy). Reposition accuracy was measured as a mean absolute error (the difference between criterion position and matching position). Ten separate attempts were made to duplicate the original neutral spine position in standing. Each trial began with pelvis movement in the posterior direction to anterior direction then finding the neutral position. The neutral position was held for the remaining time of each trial. The speed of the participant's motion was controlled via verbal commands by the investigator. Again, there was approximately one minute

between trials in which the participants stood in a relaxed position shifting the weight from side to side.

Neutral Spine – Seated

Elgon Prep and Placement - Seated

Participants sat unsupported on a chair with hips and knees placed at 90° of flexion. The foot placement was outlined on the floor with chalk. Arms remained relaxed at the sides. The elgon remained along the midline of the lumbosacral spine and checked for movement.

Extreme Anterior and Posterior Pelvic Tilt - Seated

Participants were instructed to sit with the arms at the sides tilting their pelvis into extreme posterior and anterior pelvic tilt. The examiner prompted them to "rotate the hip dial backwards to flatten the back" then "rotate the hip dial forward" as far as they could without feeling any pain. Participants then returned to a relaxed sitting position. The extreme ranges of motion (TROM) were collected in a single trial lasting 10-seconds, where the speed of the participant's motion was controlled via verbal commands by the investigator. The condition was repeated three times, with approximately one minute between each trial.

Baseline Neutral Measurement- Seated

Following TROM measurements, the baseline neutral spine measurement was obtained. Baseline was established as an average of three separate 10-second

repetitions. Each repetition consisted of posterior to anterior pelvic positioning followed by obtaining the individualized neutral spine position as previously defined in the Instrumentation and Methodology section. Once neutral was obtained, individuals were instructed to hold that position for the remaining time of the trial. The speed of the participant's motion was controlled via verbal commands by the investigator. There was approximately one-minute between trials in which participants sat in a relaxed supported position. The calculated average of the three repetitions then served as the reference criterion upon which all subsequent seated trials were compared.

Repositioning Accuracy - Seated

As stated in the above section, proprioception was measured by the ability of the participant to reposition the pelvis into a neutral position (reposition accuracy). Reposition accuracy in the seated position was measured as a mean absolute error (the difference between criterion position and matching position). Ten separate attempts were made to duplicate the original seated neutral spine position. Each trial began with pelvis movement in the posterior direction to anterior direction then finding the neutral position. The neutral position was held for the remaining time of each trial. The speed of the participant's motion was controlled via verbal commands by the investigator. There was approximately one-minute between trials in which participants sat in a relaxed supported position.

Data Reduction and Analysis

Raw electrogoniometric signals were amplified as described previously in the Instrumentation and Methodology section. Following amplification, the signals underwent analog to digital conversion at 200 Hz using a 12-bit, 16-channel analog-to-digital converter (A/D) board connected to the Ariel Performance Analysis System (APAS; Ariel Dynamics, Inc.). The signals from the elgon were checked visually on a screen before and frequently during the testing. All trials were exported and saved into ASCII text files and subsequently imported into a spreadsheet (Microsoft ® Excel 2000, Microsoft Corporation) for further analyses. The full 10-second trial was used for analyses of TROM trials in standing and seated conditions. Only that portion of the curve where neutral was obtained and held was used for analyses of neutral baseline postures and repositioning trials for standing and seated conditions.

Statistics

Descriptive statistics were performed on all variables. Repositioning accuracy was recorded as the absolute mean error (mean difference between criterion and matching positions ignoring direction of error). A 2x10x2 repeated measures ANOVA (group x trials x conditions) was used to examine between trial differences within and between groups, for the mean absolute repositioning values. A two factor repeated measures ANOVA (group x time) was used to examine differences in lumbar lordosis obtained with the flexible ruler. Multivariate analyses of variance (MANOVA) were

used to determine group differences for the demographic, anthropometric, flexibility, strength, total lumbar range of motion (standing and sitting), and baseline neutral spine posture (standing and sitting). Post hoc tests were performed when indicated using Tukey's HSD. Finally the relationships between CLBP, repositioning accuracy, and other variables (demographics, flexibility, and strength) were examined using Spearman's correlations since normality was not assumed. The CLBP group was also divided into two sub-groups (High and Low CLBP) to examine trends in the amount of CLBP disability. All statistical computations were completed using SPSS statistical software package, version 10.0 (SPSS, Inc., Chicago, Illinois, 2000). Statistical significance for all tests was established at $p < 0.05$.

CHAPTER FOUR

RESULTS

The primary purpose of this study was to compare repositioning accuracy of individuals with chronic low back pain (CLBP) and healthy controls. Specifically, the ability to reposition the pelvis into a neutral position was examined in standing and seated positions. A secondary purpose of the study was to examine the inter-relationships between low back pain, repositioning accuracy and select physical measurements. To examine this comparison, 19 subjects (9 CLBP and 10 controls) between the ages of 35 and 55 years old were grouped based on their Oswestry Low Back Pain Disability (ODQ) score. Both males and females participated in this study. There were a total of four males in the control group; there were no males in the CLBP group. The following pelvic positions were measured with an electronic gonoiometer (elgon) while subjects were standing and sitting: 1) Total Lumbar Range of Motion (TROM), 2) Baseline Neutral Position, and 3) Neutral Repositioning.

It was hypothesized that individuals with CLBP would not be able to repeat their neutral spine position as accurately as the controls in both standing and sitting positions. In addition, it was hypothesized that individuals with CLBP would overshoot their neutral position due to proprioceptive deficits. Furthermore, it was hypothesized that the magnitude of repositioning error would be smaller in the seated position for both groups as compared to standing due to increased proprioceptive input from the contact with the chair.

Differences within the CLBP individuals were discovered during the statistical process. To further investigate those differences, individuals in the CLBP were divided into high and low CLBP groups based on their ODQ Index. Individuals with an ODQ score lower than 10 were placed in the low CLBP group. Individuals with an ODQ score greater than 10 were placed in the high CLBP group. Results for these analyses are described in the last section of this chapter.

Demographic Information

Multivariate analyses of variance (MANOVA) were conducted between groups for age, height, weight, estimated body fatness, body mass index, and torso length. Significance was set at $p \leq 0.05$ for all statistical analyses. Significant differences are indicated within each of the tables.

Descriptive statistics for age, height, weight, estimated body fatness, body mass index, and torso length are presented in Table 4.1. MANOVA indicated that the groups were similar with regards to age, height, weight and torso length. The CLBP individuals had a statistically higher estimated body fat percentage than the control group ($p < 0.05$). In addition, the CLBP group had a slightly higher body mass index compared to the control group; however, the difference was not statistically significant.

Table 4.1. Physical Characteristics of Individuals with Chronic Low Back Pain (CLBP) and Controls*

	Age (yr)	Height (m)	Weight (kg)	Est BF (%)	BMI (kg/m^2)	TL (cm)
CLBP (n=9)	44.44 ± 5.27	1.66 ± 0.01	86.41 ± 28.38	34.68** ± 9.22	31.01 ± 8.92	45.9 ± 3.52
Control (n=10)	44.20 ± 8.26	1.71 ± 0.13	78.96 ± 15.77	26.10 ± 9.26	27.10 ± 3.98	47.88 ± 5.91

** Means ±SD, ** $p < 0.05$*
Est BF = Estimated body fatness taken via skinfold calipers
BMI = Body Mass Index
TL = Torso Length

Lumbar Lordosis

Lumbar lordosis curvature was measured using a flexible ruler in a standing posture. The results for lumbar curvature (flexible ruler relaxed and flexible ruler neutral) are reported in Table 4.2. To examine the difference in lumbar lordosis before and after neutral spine training, a two factor (group x time) repeated measures ANOVA was performed on the measurements obtained with the flexible ruler. There was a significant main effect for time in both the CLBP and control groups; the lumbar lordosis measures were significantly reduced with neutral spine posture. The between group effect was not significant. Figure 4.1 provides a graphical representation of the average pre- and post-neutral spine posture.

Table 4.2. Lumbar Curvature in Relaxed and Neutral Standing Position for Individuals with CLBP and Controls*

	Lumbar Curvature†	
	Relaxed Standing (°)	Neutral Standing (°)
CLBP (n=9)	54.76 ± 12.69	47.60** ± 17.77
Control (n=10)	50.92 ± 8.18	45.64** ± 5.07

**Means ± SD, ** $p < 0.05$*
†Lumbar curvature taken in standing position with flexible ruler

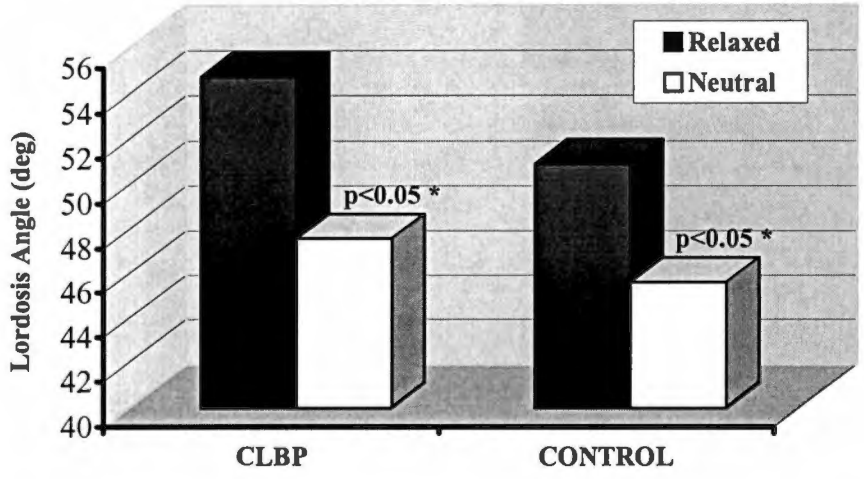

Figure 4.1. Flexible Ruler Measures of Lumbar Lordosis in CLBP and Controls
** $p < 0.05$*

Self-Reported Information

Physical Activity

The results for self-reported physical activity are reported in Table 4.3. MANOVA indicated that the CLBP and control groups did not statistically differ with the number of minutes per week spent performing physical activity ($p = 0.53$). Both

groups demonstrated a large variation in the number of minutes of physical activity performed during a week.

Oswestry Low Back Pain Disability Questionnaire

The results for Oswestry Low Back Pain Disability Questionnaire (ODQ) are reported in Table 4.3. The CLBP group demonstrated a significantly higher ODQ score than the control group; nevertheless they exhibited minimal disability (x=23.78%) according to the ODQ index[28].

Table 4.3. Self-Reported Characteristics of Individuals with CLBP and Controls*

	PA (min/wk)	ODQ Index (%)
CLBP (n=9)	163.89 ± 111.96 (30.00 – 390.00)	23.78 ± 26.20** (2.00 – 68.00)
Control (n=10)	260.00 ± 174.93 (80.00 – 630.00)	0.00 ± 0.00 N/A

Means ±SD (Minimum-Maximum), ** $p < 0.05$
PA = Physical Activity
ODQ Index = Oswestry Low Back Pain Disability Score

Self-Reported Diagnosed Spine Conditions

Participants were asked to report on their medical history form all spine conditions that had been diagnosed by a physician. A description of the diagnosed spine conditions of the CLBP group is contained in a frequency distribution (Table 4.4). All CLBP individuals were free from acute injury at the time of their participation in the study. Conditions reported by the control group included sciatica (n = 1), leg length inequality (n = 1), and lumbar muscle strain (n = 1). However, they reported that these

Table 4.4. Frequency Distribution of Self-Reported Diagnosed Spine Conditions Among CLBP Individuals

Condition	Frequency	% of Responses
Sciatica	4	26.7
Herniated Disc	1	6.7
Scoliosis	1	6.7
DJD	2	13.2
Lumbar Muscle Strain	4	26.7
Other	3	20.0
Total Responses	**15**	**100.0**

n=9
Note: Some individuals reported more than one diagnosed spine condition.
DJD = Degenerative Joint Disease

conditions were diagnosed at least one year prior to their participation in the study; and that they were presently asymptomatic. Three individuals in the CLBP group also reported conditions classified as "other" that included fibromyalgia (cervical and thoracic regions), muscle soreness and postural problems.

Flexibility Measurements

Flexibility measurements (hamstring flexibility, hip flexor length and lumbar range of motion) can be found in Table 4.5. Lumbar spine flexion and extension were measured using the double inclinometer method[53]. Hamstring length was assessed using the passive straight leg raise measured with an inclinometer[53]. Hip flexor length was evaluated using a universal hand-held goniometer and the one-joint Thomas test[54].

Table 4.5. Flexibility Measures of Individuals with CLBP and Controls*

	Flexibility				
	SLR (°)		Thomas Test (°)		Lumbar ROM† (°)
	Right	Left	Right	Left	
CLBP (n = 9)	70.70 ± 19.54	71.03 ± 19.98	9.92 ± 4.93	9.71 ± 4.50	44.76 ± 16.89
Control (n = 10)	82.63 ± 6.95	80.24 ± 9.46	4.24 ± 4.38	4.34 ± 3.55	46.77 ± 17.48

** Means ±SD,*
† Lumbar ROM measured with double inclinometer
SLR = Straight leg raise; hamstring flexibility
Thomas Test = Hip flexor length
ROM = Range of motion

MANOVA indicated no significant differences in lumbar ROM, hip extensor, and hip flexor flexibility between the groups ($p = 0.78$). It is interesting to note that on average, the CLBP subjects had decreased hamstring length compared to the controls. In addition, the CLBP individuals had greater hip flexor tightness than the controls; however, these differences were not significant.

Strength Measurements

The results for strength measurements can be found in Table 4.6. These measuring techniques are described by Kendall and McCreary [54] and include trunk flexion strength using the double-leg lowering test as well as manual muscle tests (MMT) for hip flexors, hip extensors and trunk extensors. The MMT are scored on a one to five-point scale, with the score of five, representing normal strength [54]. The double-leg lowering test is scored in degrees; in this test the smaller the score, the better the abdominal muscle strength. MANOVA indicated significant differences between

Table 4.6. Strength Measures of Individuals with CLBP and Controls*

	Strength					
	Hip Flexion†		Hip Extension†		Trunk Ext†	Trunk Flex (°)
	Right	Left	Right	Left		
CLBP (n = 9)	4.67 ± 0.50	4.78 ± 0.44	4.78 ± 0.44	4.89 ± 0.33	4.22** ± 0.67	68.85** ±18.27
Control (n = 10)	4.90 ± 0.32	4.80 ± 0.42	4.90 ± 0.32	4.90 ± 0.32	4.90 ± 0.32	41.68 ± 16.73

** Means ±SD, ** p < 0.05*
† Manual Muscle Testing (MMT)
Trunk Ext = Trunk Extension
Trunk Flex = Abdominal strength tested via double leg lowering

the groups in strength (p = 0.04). Tukey's post hoc indicated no significant differences between groups for hip flexor (right and left) strength (p = 0.23 and p = .91). In addition there were no significant differences for hip extension (right and left) strength (p = 0.49 and p = .94). However, there were statistically significant differences between groups in trunk extension strength and trunk flexion strength (p = 0.01and p = .004). In both cases, the CLBP had statistically weaker trunk extension and abdominal muscle strength indicated by a lower mean trunk extension score and a higher double leg lowering score.

Repositioning Accuracy

Repositioning measures (total range of motion, baseline neutral and mean absolute repositioning error) were recorded using an electrogoniometer (elgon). The orientation of the elgon resulted in raw posterior pelvic tilt to be recorded as positive integers. Anterior pelvic tilt was recorded in negative integers. Figure 4.2 shows a typical total range of motion trial in standing for an individual without LBP. The first

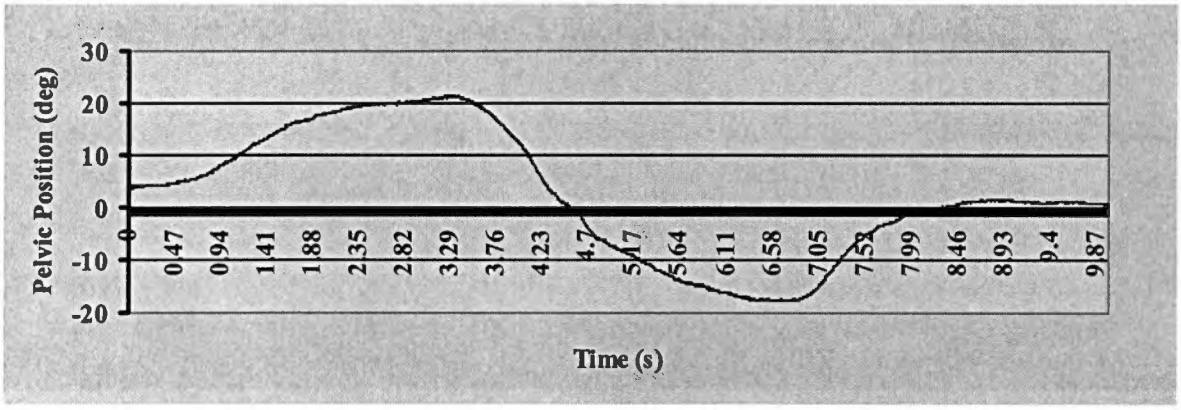

Figure 4.2. Typical Total Range of Motion Curve in Standing for an Individual Without Low Back Pain.

part of the curve represents the individual moving into a posterior pelvic tilt (positive score). As the individual moves into anterior pelvic tilt, the curve becomes negative.

To examine between trial differences within and between groups, repeated measures ANOVA (2x10x2) was performed on the mean absolute repositioning values. No significance differences were demonstrated for group x trials x condition ($p = 0.48$), condition x rep ($p = 0.25$), group x trial ($p = 0.82$), trials ($p = 0.27$), and group x condition ($p = 0.64$). Therefore, mean repositioning scores for both standing and seated positions were used for subsequent analyses. Estimated marginal means for each group in each condition are shown in Figures 4.3 and 4.4. The primary hypothesis that mean absolute repositioning error (RE) would be higher in subjects with CLBP than in controls was not demonstrated in this study with a repeated measures ANOVA analysis.

There was a significant difference between conditions (standing vs. seated) for all subjects ($p < 0.05$). Repeated measures ANOVA with 9 subjects in the CLBP group and 10 subjects in the control group, demonstrated 72% power to detect a difference in mean absolute RE between the conditions. This is considered to be a moderate effect.

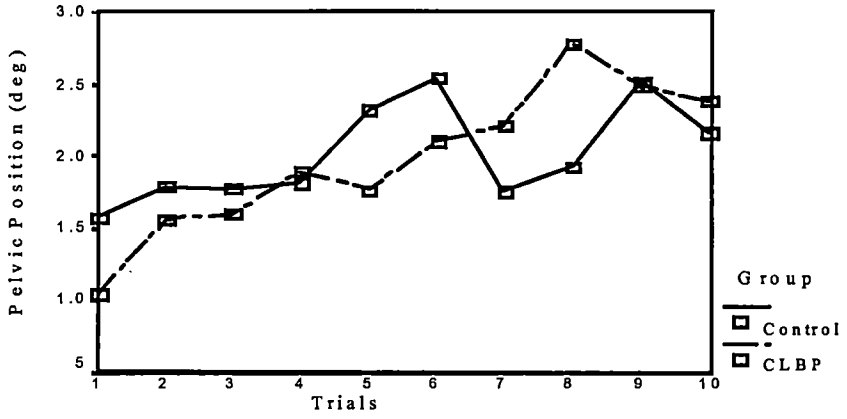

Figure 4.3. Mean Error per Trial for Repositioning in Standing Position

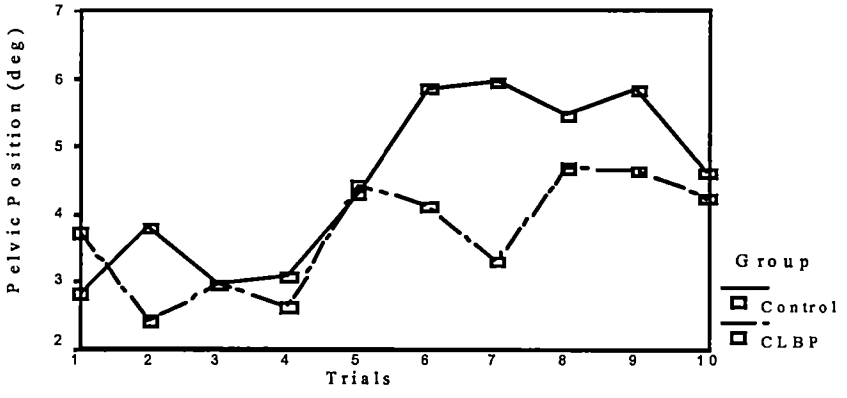

Figure 4.4. Mean Error per Trial for Repositioning in Seated Position

Overall, for all subjects, the mean absolute repositioning error was greater in a seated position than in standing. The mean absolute repositioning error in standing for the control group was 2.01° (± 0.714) and 1.99° (± 1.04) for the CLBP group. In sitting, the mean absolute repositioning error for the control group was 4.47° (± 3.24) and 3.72° (± 2.55) for the CLBP group. Therefore, the hypothesis that the magnitude of repositioning error would be smaller in the seated position in both groups as compared to standing due to increased proprioceptive input was not demonstrated in this study.

However, when actual raw repositioning values were used in the analyses, the condition effect was eliminated for all subjects.

Standing

The electrogoniometer (elgon) was used to measure standing total range of motion (TROM), neutral baseline, and mean repositioning accuracy. TROM was calculated as the combination of extreme posterior pelvic tilt and extreme anterior pelvic tilt. The average of three trials was used as the baseline measure of the individual's neutral spine position. The difference between the baseline neutral position and the repositioning trial was used as the repositioning score. MANOVA indicated that the differences were not significant for standing TROM, baseline neutral posture or mean absolute repositioning error ($p = 0.79$).

Standing Total Range of Motion (TROM)

The results for standing TROM can be found in Table 4.7. Individuals with CLBP demonstrated a smaller range of pelvic motion. The large standard deviations demonstrated substantial variation within both groups.

Table 4.7. Standing Measures of Total Range of Motion, Baseline Neutral and Repositioning Error for Individuals with CLBP and Controls*

	TROM (°)	Baseline Neutral Position (°)	Mean Absolute RE (°)
CLBP (n = 9)	23.20 ± 17.19	2.54 ± 2.75	1.99 ± 1.04
Control (n = 10)	31.69 ±15.70	2.95 ± 2.74	2.02 ± 0.71

** Means ± SD*
TROM = Total Range of Motion in Standing
RE = Mean Absolute Repositioning Error

Baseline Neutral Standing Position

The results for baseline neutral standing position can also be found in Table 4.7. Individuals with CLBP demonstrated a similar neutral standing position compared to the control group. In standing, controls were slightly more lordotic than the individuals in the CLBP group; however, the two groups were not statistically different. Similar to standing TROM, the variations from the mean are large in both groups in comparison to the mean.

Mean Absolute Repositioning Error (RE) in Standing

The results for mean absolute repositioning error (RE) in standing can also be found in Table 4.7. Individuals with CLBP demonstrated a slightly smaller mean absolute repositioning error than the controls; however the two groups were not statistically different in mean absolute RE in standing. Comparisons of mean absolute RE and mean repositioning raw score are presented in Figure 4.5. The raw values for standing repositioning demonstrated that the CLBP group had less RE than the controls when repositioning into their neutral position.

Seated

Measurements for seated total range of motion (TROM), neutral baseline and mean repositioning accuracy were taken using the elgon. TROM was calculated as the combination of extreme posterior pelvic tilt and extreme anterior pelvic tilt. The average of three trials was used as the baseline measure of the individual's neutral spine position. The difference between the baseline neutral position and the repositioning

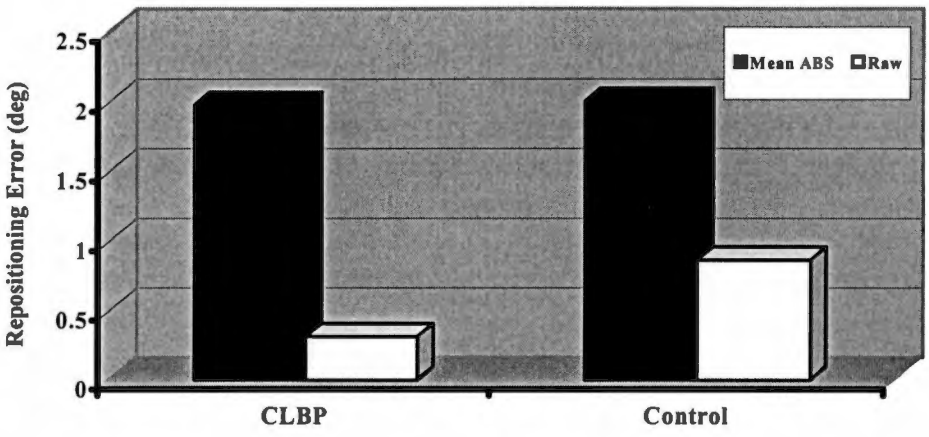

Figure 4.5. Mean Repositioning Error (Mean ABS and Raw values) for Standing in CLBP and Controls

Mean ABS = Mean absolute repositioning error

trial was used as the repositioning score. MANOVA indicated that the differences were not significant for sitting TROM, baseline neutral posture or mean absolute repositioning error ($p = 0.79$).

Seated Total Range of Motion (TROM)

The results for seated TROM can be found in Table 4.8. Similar to standing TROM, individuals with CLBP demonstrated a slightly smaller range of pelvic motion; however, the differences were not significant between the groups. Again, there was a large amount of variation within the two groups.

Table 4.8. Seated Measures of Total Range of Motion, Baseline Neutral and Repositioning Error for Individuals with CLBP and Controls*

	TROM (°)	Baseline Neutral Position (°)	Mean Absolute RE (°)
CLBP (n = 9)	33.28 ± 14.97	15.35 ± 13.95	3.72 ± 2.55
Control (n = 10)	36.78 ± 17.80	10.70 ± 9.71	4.47 ± 3.24

**** Means ± SD***
TROM = Total Range of Motion in Seated Position
RE = Mean Absolute Repositioning Error

Baseline Neutral Seated Position

The results for baseline neutral seated position can be found in Table 4.8. Individuals with CLBP demonstrated a slightly less lordotic neutral position while seated than the controls; however, the two groups were not statistically different in the baseline neutral position comparison. The intra-group variation was substantial.

Mean Absolute Repositioning Error (RE) in Seated Position

The results for mean absolute repositioning error (RE) in a seated position can also be found in Table 4.8. Individuals with CLBP demonstrated a lower absolute mean RE than the control group in a seated position; however, that the two groups were not statistically different. Comparisons of mean absolute RE and mean raw repositioning values for the seated position are presented in Figure 4.6. When raw values are considered, the CLBP group on average repositioned approximately one degree more posteriorly tilted than the baseline position whereas the controls tended to reposition their pelvis more anteriorly than their baseline by approximately two degrees.

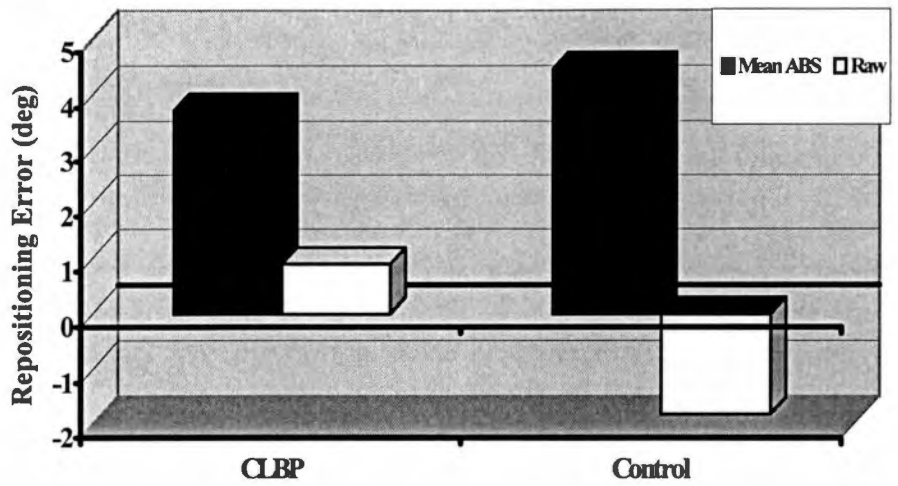

Figure 4.6. Mean Repositioning Error (absolute and raw) for Seated in CLBP and Controls

Mean ABS = Mean absolute repositioning error

Percentages of Undershooting and Overshooting Neutral

The percentage of "undershooting" and "overshooting" of the baseline neutral positions of individuals with CLBP and the control subjects in both standing and seated positions are presented in Table 4.9. An individual that repositioned the pelvis within a range of - 0.999 to 0.999° of his/her baseline neutral position was recorded as positioning into neutral. The percentages in Table 4.9 are based on all trials in each group (CLBP = 90; Control = 100). In standing, the control group tended to undershoot the neutral position (55%) whereas the CLBP group presented a somewhat even distribution across the three areas. In a seated position, the control group overshot neutral in over half of the trials. There was an almost equal percentage of

Table 4.9. Repositioning Accuracy in Individuals with CLBP and Controls

	Standing		Seated	
	Control (n = 100)	CLBP (n = 90)	Control (n = 100)	CLBP (n = 90)
Overshot (%)	22.0	33.3	54.0	40.0
Neutral (%)	23.0	30.0	21.0	17.8
Undershot (%)	55.0	36.7	25.0	42.2

undershooting and overshooting in the seated neutral position in individuals with CLBP.

Relationships Between Low Back Pain (LBP), Repositioning Measures, and Other Physical Measures

Spearman rank correlations were performed to investigate the relationships between selected variables. The Oswestry Low Back Pain Disability Index (ODQ) was used as a CLBP variable to investigate potential relationships between CLBP, repositioning measures (i.e., TROM, neutral, and repositioning error), and other physical measures (i.e., anthropometric, flexibility, and strength measures). Significance for correlation analyses was established at $p < 0.05$. In general, the correlation values were moderate to low for all relationships.

There were no relationships investigated between LBP and repositioning measures or the physical measures for the control group. By definition of the groups, the control group had an ODQ index of zero, therefore, only LBP relationships for the CLBP are reported in the following sections.

Relationships between Chronic Low Back Pain and Repositioning Measures

Correlation between CLBP and repositioning measures (TROM, Baseline Neutral, and mean absolute repositioning error) in standing and seated positions were low, ranging from -.087 to -.591. CLBP was not significantly correlated with any of the standing or seated repositioning measures in the CLBP group. In general, the level of CLBP did not affect an individual's total lumbar range of motion, their neutral position, or their ability to reposition the spine into their neutral position. The correlations for these variables can be found in Table 4.10.

Table 4.10. Relationships between ODQ Score and Repositioning Measures for the CLBP Group

	Stand TROM	Stand Neutral	Stand Reposition	Seated TROM	Seated Neutral	Seated Reposition
ODQ Score CLBP (n=9)	r =-.323 p = 0.56	r =-.254 p = 0.88	r =.186 p = 0.68	r =-.591 p = 0.07	r =-.087 p = 0.63	r =-.100 p = 0.89

TROM = Total Range of Motion

Relationships between Chronic Low Back Pain and Other Physical Measures

Physical measures are divided into anthropometric measures including self-reported physical activity, flexibility measures, and strength measures.

Anthropometric

There were no statistically significant relationships found between ODQ score and any of the anthropometric measures for the CLBP group (Table 4.11). These correlations ranged from .021 to .569. Weight, estimated body fat, and body mass index demonstrated moderate correlations; however, they were not significant.

Table 4.11. Relationships between ODQ Score and Anthropometric Measures for the CLBP Group

	Age (yr)	Ht (m)	Wt (kg)	Est BF (%)	BMI (kg/m^2)	PA (min/wk)	TL (cm)
ODQ Score	r =.392	r =.033	r =.544	r =.569	r =.552	r =-.131	r =.021
CLBP (n=9)	p = 0.29	p = 0.93	p = 0.13	p = 0.11	p = 0.12	p = 0.74	p = 0.96

Ht = Height
Wt = Weight
Est BF = Estimated body fatness taken via skinfold calipers
BMI = Body Mass Index
TL = Torso Length

Flexibility

The results demonstrated statistically significant relationships between ODQ score and bilateral straight leg raise and Thomas test for the right lower extremity for the CLBP group. There was a moderate inverse correlation between ODQ score and SLR measures for the right and left lower extremity. This relationship indicates that low back pain increased with decreased flexibility in the hamstrings. In addition, ODQ was moderately correlated with Thomas test for the right leg. This relationship indicates that individuals with tight hip flexors reported more LBP. Correlation between the ODQ score and Thomas test for the left lower extremity was moderate but not significant. The correlations for the flexibility variables can be found in Table 4.12.

Strength

There were no statistically significant relationships between ODQ score and any of the manually tested strength tests (hip flexion, hip extension and trunk extension). Correlations for these variables ranged from -.208 to -.624. Conversely, there was a moderate to high correlation between ODQ and double leg lowering test for abdominal strength. It should be re-emphasized that the abdominal muscle strength test is scored

Table 4.12. Relationships between ODQ Score and Flexibility Measures for the CLBP Group

	Flex Relax	Flex Neutral	SLR_R	SLR_L	Thomas Test_R	Thomas Test_L	Lumbar ROM
ODQ Score CLBP (n =9)	r =-.301 p = 0.43	r =-.335 p = 0.38	**r =-.728 p =0.02****	**r =-.745 p =0.02****	**r =.695 p =0.03****	r =.580 p = 0.10	r =-.477 p = 0.19

***** p < 0.05***
SLR_R=Straight leg raise right leg
SLR_L= Straight leg raise left leg

in degrees, and in this test, the smaller the score, the greater the abdominal strength. The correlation between these two variables demonstrated that individuals with decreased abdominal strength reported higher disability scores due to LBP. The relationships between ODQ score and strength measures for the CLBP group are contained in Table 4.13.

Repositioning Measures and Other Physical Measures

Relationship between Standing Repositioning Measures and Anthropometric Measures

Repositioning measures included standing total range of motion (TROM), baseline standing neutral, and mean absolute repositioning error (RE) in a standing position. There were no statistically significant relationships between standing repositioning measures and anthropometric measures for the CLBP group. The correlations ranged from .008 to -.538 for TROM, -.067 to -.437 for neutral, and -.033 to .510 for repositioning accuracy.

The control group did not demonstrate any statistically significant relationships between standing repositioning measures and anthropometric measures. The

Table 4.13. Relationships between ODQ Score and Strength Measures for the CLBP Group

	Hip Flex_R	Hip Flex_L	Hip Ext_R	Hip Ext_L	Trunk Ext	Trunk Flexion
ODQ Score CLBP (n =9)	r =-.458 p = 0.21	r =-.208 p = 0.59	r =-.624 p = 0.07	r =-.275 p = 0.47	r =-.449 p = 0.22	**r =.769 p =0.01****

***p < 0.05*

correlations ranged from -.139 to -.345 for TROM, -.018 to -.607 for neutral, and -.006 to -.153 for repositioning accuracy. The correlations for both groups are presented in Table 4.14.

Relationship between Standing Repositioning Measures and Flexibility Measures

Correlations between repositioning measures in standing and flexibility for the CLBP group ranged from -.033 to .700 for TROM, -.017 to .600 for neutral, and -.067 to -.400 for repositioning accuracy. Statistical significance was only present in the relationship between standing TROM and hamstring flexibility on the right side. The results indicated a moderate relationship between neutral position and hamstring flexibility on the right side; however, this relationship was not significant.

In the control group, statistical significance was present in the relationship between standing TROM and lumbar range of motion. The correlations ranged from -.110 to -.457 for TROM, -.103 to .624 for neutral, and -.212 to -.624 for repositioning accuracy. The correlations for both groups are presented in Table 4.15.

Table 4.14. Relationships between Standing Repositioning Measures and Anthropometric Measures for the CLBP and Control Groups

CLBP (n=9)	Age (yr)	Ht (m)	Wt (kg)	Est BF (%)	BMI (kg/m^2)	PA (min/wk)	TL (cm)
TROM	r =-.067 p = 0.86	r =-.233 p = 0.54	r =-.467 p = 0.20	r =-.417 p = 0.26	r =-.467 p = 0.20	r =-.538 p = 0.13	r =.008 p = 0.98
Neutral	r =-.084 p = 0.83	r =-.333 p = 0.38	r =-.283 p = 0.46	r =-.067 p = 0.86	r =-.200 p = 0.60	r =.-.437 p = 0.24	r =-.192 p = 0.62
Repositioning	r =.412 p = 0.27	r =-.083 p = 0.83	r =-.033 p = 0.93	r =-.033 p = 0.93	r =.067 p = 0.86	r =.202 p = 0.60	r =.510 p = 0.16
CONTROL (n=10)	**Age (yr)**	**Ht (m)**	**Wt (kg)**	**Est BF (%)**	**BMI (kg/m^2)**	**PA (min/wk)**	**TL (cm)**
TROM	r =-.251 p = 0.55	r =-.345 p = 0.32	r =-.297 p = 0.40	r =-.139 p = 0.70	r =-.200 p = 0.58	r =-.190 p = 0.59	r =.146 p = 0.68
Neutral	r =-.607 p = 0.06	r =-.018 p = 0.96	r =-.139 p = 0.70	r =-.285 p = 0.42	r =.055 p = 0.88	r =-.399 p = 0.25	r =.316 p = 0.37
Repositioning	r =-.153 p = 0.67	r =-.006 p = 0.98	r =.115 p = 0.75	r =-.006 p = 0.98	r =.200 p = 0.58	r =-.006 p = 0.98	r =-.109 p = 0.76

Ht = Height
Wt = Weight
Est BF = Estimated body fatness taken via skinfold calipers
BMI = Body Mass Index
TL = Torso Length

Table 4.15. Relationships between Standing Repositioning Measures and Flexibility Measures for the CLBP and Control Groups

CLBP (n=9)	Flex Relax	Flex Neutral	SLR_R	SLR_L	Thomas Test_R	Thomas Test_L	Lumbar ROM
TROM	r .367 p = 0.33	r =.100 p = 0.79	**r =.700 p = .036****	r =.617 p =0.07	r =-.033 p = 0.93	r =.192 p = 0.62	r =-.083 p = 0.83
Neutral	r =.533 p = 0.13	r =.200 p = 0.60	r =.600 p = 0.08	r =.450 p =0.22	r =-.017 p = 0.96	r =.084 p = 0.83	r =-.017 p = 0.96
Repositioning	r =-.083 p = 0.83	r =.350 p = 0.35	r =-.400 p = 0.28	r =-.400 p =0.28	r =.300 p = 0.43	r =.318 p = 0.40	r =-.067 p = 0.86
CONTROL (n=10)	**Flex Relax**	**Flex Neutral**	**SLR_R**	**SLR_L**	**Thomas Test_R**	**Thomas Test_L**	**Lumbar ROM**
TROM	r =-.158 p = 0.66	r =-.297 p = 0.40	r =.310 p = 0.38	r =.457 p =0.18	r =-.252 p = 0.48	r =-.110 p = 0.76	r =.212 p = 0.55
Neutral	r =-.109 p = 0.76	r =-.103 p = 0.77	r =.116 p = 0.75	r =.305 p =0.39	r =-.332 p = 0.34	r =-.122 p = 0.73	**r =.624 p = .05****
Repositioning	r =-.383 p = 0.27	r =-.297 p = 0.40	r =-.012 p = 0.97	r =-.451 p =0.19	r =.406 p = 0.24	r =.404 p = 0.24	r =-.212 p = 0.55

***** p < 0.05***
SLR_R=Straight leg raise right leg
SLR_L= Straight leg raise left leg

Relationship between Standing Repositioning Measures and Strength Measures

There were no statistically significant relationships between standing repositioning measures and strength measures for the CLBP group. The correlations ranged from .104 to .548 for TROM, .000 to .411 for neutral, and .104 to -.429 for repositioning accuracy.

The control group did not demonstrate any statistically significant relationships between standing repositioning measures and strength measures. The correlations ranged from -.087 to -.571 for TROM, .000 to -.298 for neutral, and -.058 to .286 for repositioning accuracy. The correlations for both groups are presented in Table 4.16.

Relationship between Seated Repositioning Measures and Anthropometric Measures

Correlations between repositioning measures in a seated position and anthropometric measures for the CLBP group ranged from .008 to -.850 for TROM, .067 to -.483 for neutral, and -.083 to -.483 for repositioning accuracy. Statistical significance was present in the relationships between seated TROM and estimated body fat and body mass index for the CLBP group. These correlations indicated that the higher the body fat percentage or body mass index the less total range of motion the individuals had in a seated position.

There were no statistically significant relationships between seated repositioning measures and anthropometric measures for the control group. The correlations ranged from -.080 to -.539 for TROM, -.006 to -.399 for neutral, and .006 to -.200 for repositioning accuracy. The correlations for both groups are presented in Table 4.17.

Table 4.16. Relationships between Standing Repositioning Measures and Strength Measures for the CLBP and Control Groups

CLBP (n=9)	Hip Flex_R	Hip Flex_L	Hip Ext_R	Hip Ext_L	Trunk Ext	Trunk Flexion
TROM	r =.274 p = 0.47	r =.104 p = 0.79	r =.311 p = 0.41	r =.548 p = 0.12	r =.298 p = 0.43	r =-.477 p = 0.19
Neutral	r =.365 p = 0.33	r =-.000 p = 1.00	r =-.104 p = 0.79	r =.411 p = 0.27	r =.093 p = 0.81	r =-.343 p = 0.36
Repositioning	r =-.183 p = 0.63	r =.207 p = 0.59	r =.104 p = 0.79	r =-.137 p = 0.72	r =-.429 p = 0.25	r =.134 p = 0.73
CONTROL (n=10)	**Hip Flex_R**	**Hip Flex_L**	**Hip Ext_R**	**Hip Ext_L**	**Trunk Ext**	**Trunk Flexion**
TROM	r =.290 p = 0.41	r =-.087 p = 0.81	r =.290 p = 0.41	r =.290 p = 0.41	r =.290 p = 0.41	r =-.571 p = 0.08
Neutral	r =.174 p = 0.63	r =.000 p = 1.00	r =.174 p = 0.63	r =.174 p = 0.63	r =.174 p = 0.63	r =-.298 p = 0.40
Repositioning	r =.058 p = 0.87	r =-.087 p = 0.81	r =-.058 p = 0.87	r =-.058 p = 0.87	r =-.058 p = 0.87	r =.286 p = 0.42

Table 4.17. Relationships between Seated Repositioning Measures and Anthropometric Measures for the CLBP and Control Groups

CLBP (n=9)	Age (yr)	Ht (m)	Wt (kg)	Est BF (%)	BMI	PA (min/wk)	TL (cm)
TROM	r =-.538 p = 0.13	r =.167 p = 0.66	r =-.600 p = 0.08	**r =-.800 p = .01****	**r =-.850 p = .004****	r =-.193 p = 0.61	r =.008 p = 0.98
Neutral	r =.134 p = 0.73	r =-.483 p = 0.18	r =.067 p = 0.86	r =.217 p = 0.57	r =.317 p = 0.40	r =-.429 p = 0.25	r =-.218 p = 0.57
Repositioning	r =-.168 p = 0.66	r =-.083 p = 0.83	r =-.383 p = 0.30	r =-.275 p = 0.18	r =-.483 p = 0.30	r =-.383 p = 0.63	r =.402 p = 0.28
CONTROL (n=10)	**Age (yr)**	**Ht (m)**	**Wt (kg)**	**Est BF (%)**	**BMI**	**PA (min/wk)**	**TL (cm)**
TROM	r =-.080 p = 0.82	r =-.515 p = 0.12	r =-.539 p = 0.10	r =-.115 p = 0.75	r =-.139 p = 0.70	r =-.043 p = 0.90	r =-.134 p = 0.71
Neutral	r =-.399 p = 0.25	r =.261 p = 0.46	r =.261 p = 0.46	r =-.200 p = 0.58	r =-.006 p = 0.98	r =.055 p = 0.98	r =.280 p = 0.43
Repositioning	r =.092 p = 0.80	r =-.200 p = 0.58	r =-.139 p = 0.70	r =-.200 p = 0.58	r =-.164 p = 0.65	r =.006 p = 0.28	r =.128 p = 0.72

***** p < 0.05***
Ht = Height
Wt = Weight
Est BF = Estimated body fatness taken via skinfold calipers
BMI = Body Mass Index
TL = Torso Length

Relationship between Seated Repositioning Measures and Flexibility Measures

Correlations between repositioning measures in seated and flexibility for the CLBP group ranged from .083 to .967 for TROM, -.083 to .700 for neutral, and .033 to -.449 for repositioning accuracy. The results indicated statistical significance present in the relationship between standing TROM and bilateral hamstring flexibility and the Thomas test for the right lower extremity. These relationships indicate that better ROM in the hamstrings and hip flexors allowed for more seated range of motion. The results indicated a significant positive relationship between neutral position and performance on the Thomas test on the right side

There were no statistically significant relationships between seated repositioning measures and flexibility measures for the control group. The correlations ranged from .037 to .585 for TROM, -.103 to -.457 for neutral, and -.128 to .463 for repositioning accuracy. The correlations for both groups are presented in Table 4.18.

Relationship between Seated Repositioning Measures and Strength Measures

The results indicated one statistically significant relationship between seated repositioning measures and strength measures for the CLBP group. There was an inverse relationship between seated TROM and abdominal strength. The correlations ranged from .207 to -.862 for TROM, .000 to .510 for neutral, and -.037 to -.548 for repositioning accuracy.

Table 4.18. Relationships between Seated Repositioning Measures and Flexibility Measures for the CLBP and Control Groups

CLBP (n=9)	Flex Relax	Flex Neutral	SLR_R	SLR_L	Thomas Test_R	Thomas Test_L	Lumbar ROM
TROM	r =.283 p = 0.46	r =.083 p = 0.83	**r =.767 p = .02****	**r =.967 p=.00****	**r =-.767 p = .02****	r =-.418 p = 0.26	r =.217 p = 0.57
Neutral	r =-.083 p = 0.83	r =-.100 p = 0.79	r =-.350 p = 0.35	r =-.500 p = 0.17	**r =.700 p = .04****	r =.569 p = 0.11	r =-.317 p = 0.40
Repositioning	r =-.183 p = 0.63	r =-.267 p = 0.48	r =.033 p = 0.93	r =.067 p = 0..86	r =-.449 p = 0.83	r =.377 p = 0.31	r =.117 p = 0.76
CONTROL (n=10)	**Flex Relax**	**Flex Neutral**	**SLR_R**	**SLR_L**	**Thomas Test_R**	**Thomas Test_L**	**Lumbar ROM**
TROM	r =-.213 p = 0.55	r =-.152 p = 0.67	r =.310 p = 0.38	r =.585 p = 0.07	r =.037 p = 0.91	r =.324 p = 0.36	r =-.212 p = 0.72
Neutral	r =-.243 p = 0.49	r =-.103 p = 0.77	r =-.140 p = 0.70	r =-.457 p = 0.18	r =.375 p = 0.28	r =.379 p = 0.28	r =.127 p = 0.70
Repositioning	r =-.128 p = 0.72	r =-.178 p = 0.62	r =.280 p = 0.80	r =.463 p = 0.43	r =-.363 p = 0.30	r =-.336 p = 0.34	r =.139 p = 0.62

***** p < 0.05***
SLR_R=Straight leg raise right leg
SLR_L= Straight leg raise left leg

In the control group, there was an inverse relationship between seated repositioning accuracy and abdominal strength. The correlations ranged from -.058 to -.348 for TROM, .030 to .435 for neutral, and .087 to -.742 for repositioning accuracy. The correlations for both groups are presented in Table 4.19.

Further Analysis between Control, Low CLBP and High CLBP

Further examination of the CLBP group demonstrated two distinct levels of disability as defined by the Oswestry Index. The CLBP group was divided into two groups based on the Oswestry Index score. Low CLBP (n = 4) included individuals that scored less than 10 on the ODQ index. High CLBP (n = 5) included individuals that

Table 4.19. Relationships between Seated Repositioning Measures and Strength Measures for the CLBP and Control Groups

CLBP (n=9)	Hip Flex_R	Hip Flex_L	Hip Ext_R	Hip Ext_L	Trunk Ext	Trunk Flexion
TROM	r =.548 p = 0.57	r =.207 p = 0.59	r =.311 p = 0.41	r =.274 p = 0.47	r =.634 p = 0.06	**r =-.862 p = .003****
Neutral	r =-.456 p = 0.40	r =-.207 p = 0.59	r =.311 p = 0.41	r =.000 p = 1.00	r =-.149 p = 0.70	r =.510 p = 0.16
Repositioning	r =-.548 p = 0.76	r =-.311 p = 0.41	r =.104 p = 0.79	r =-.274 p = 0.47	r =-.037 p = 0.92	r =.159 p = 0.68
CONTROL (n=10)	**Hip Flex_R**	**Hip Flex_L**	**Hip Ext_R**	**Hip Ext_L**	**Trunk Ext**	**Trunk Flexion**
TROM	r =-.058 p = 0.87	r =-.348 p = 0.32	r =-.058 p = 0.87	r =-.058 p = 0.87	r =-.058 p = 0.87	r =-.116 p = 0.75
Neutral	r =.406 p = 0.24	r =.435 p = 0.20	r =.406 p = 0.24	r =.406 p = 0.24	r =.406 p = 0.24	r =.030 p = 0.93
Repositioning	r =.174 p = 0.63	r =.087 p = 0.81	r =.174 p = 0.63	r =.174 p = 0.63	r =.174 p = 0.63	**r =-.742 p = .014****

*** p < 0.05***

ABD=Double leg lowering test for abdominal strength

scored greater than 10 on the index. The index score of 10 was arbitrarily chosen since the scores were distinctly higher or lower than the score of 10. Means and standard deviations for ODQ are located in Table 4.20. The three groups did not significantly differ with regards to age, height, weight, estimated body fat, body mass index, physical activity, or torso length as indicated by MANOVA (p =0.32) (Table 4.21).

Table 4.20. Mean Oswestry Index (ODQ) for All Three Groups

	Control (n = 10)	LO CLBP (n = 4)	HI CLBP (n = 5)
ODQ (%)	0.00 N/A	4.00 (2.00 - 8.00)	39.60 (10.00 – 68.00)

Table 4.21. Physical Characteristics of Controls, Low CLBP, and High CLBP*

	Age (yr)	Ht (m)	Wt (kg)	Est BF (%)	BMI (kg/m^2)	PA (min/wk)	TL (cm)
Control (n=10)	44.20 ± 8.26	1.71 ± 0.13	78.96 ± 15.77	26.10 ± 9.26	27.10 ± 3.98	260.00 ± 174.93	47.88 ± 5.91
LO CLBP (n=4)	41.50 ± 5.00	1.64 ± 0.008	72.95 ± 15.05	29.68 ± 7.08	27.18 ± 5.21	213.75 ± 146.14	47.00 ± 3.19
HI CLBP (n=5)	46.80 ± 4.60	1.68 ± 0.007	97.18 ± 33.38	38.68 ± 9.34	34.09 ± 10.60	124.00 ± 67.68	45.02 ± 3.86

Means ± SD
Ht = Height
Wt = Weight
Est BF = Estimated body fatness taken via skinfold calipers
BMI = Body Mass Index
TL = Torso Length

Flexible ruler measures for lumbar lordosis in relaxed and neutral standing are presented in Figure 4.7. Overall, there were significant differences in flexible ruler measures, flexibility measures, and strength measures ($p = 0.01$) indicated by MANOVA. Significant group differences were demonstrated for both relaxed ($p = 0.03$) and neutral ($p = 0.002$) standing positions. Tukey's post hoc revealed that the low CLBP group was less lordotic than the high CLBP group ($p = 0.04$). In neutral standing position, the control group demonstrated a significantly lower lordotic curve than the low CLBP group ($p = 0.01$). The high CLBP group demonstrated a significantly less lordotic curve than the low CLBP group ($p < 0.001$).

Results for flexibility tests are contained in Table 4.22. There were significant differences for bilateral hamstring flexibility and bilateral hip flexor length ($p<0.05$). Tukey's post hoc revealed that the control group and low CLBP group demonstrated significantly greater bilateral hamstring flexibility than the high CLBP group. The high CLBP group had significantly more hip flexor tightness than the control group.

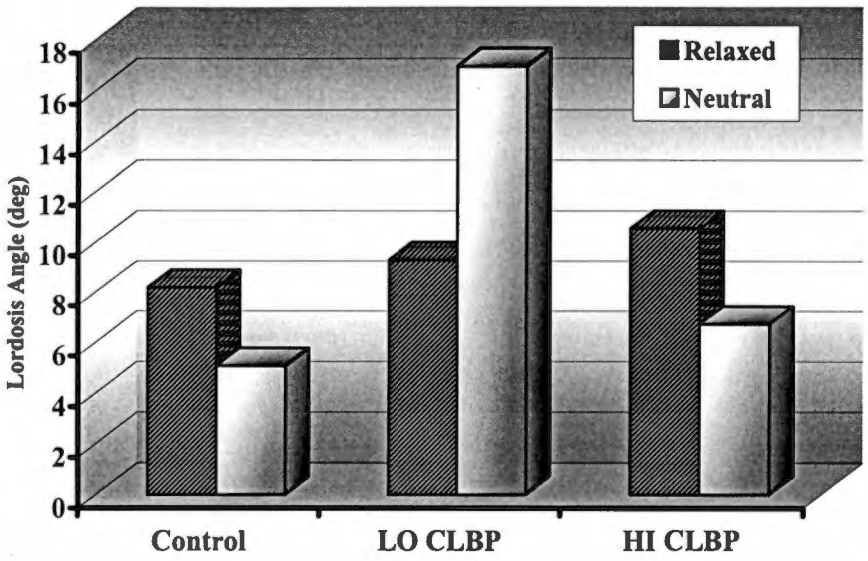

Figure 4.7. Flexible Ruler Measures of Lumbar Lordosis in Controls, LO, and HI CLBP Groups

*** $p < 0.05$**

Table 4.22. Flexibility Measures of Controls, Low CLBP, and High CLBP*

	Flexibility				
	SLR (°)		Thomas Test (°)		Lumbar ROM† (°)
	Right	Left	Right	Left	
Control (n = 10)	82.63[a] ± 6.95	80.24[a] ± 9.46	4.24[a] ± 4.38	4.34[a] ± 3.55	46.77 ± 17.48
LO CLBP (n = 4)	83.90[b] ± 17.39	83.25[b] ± 16.61	6.91 ± 4.16	7.29 ± 5.04	55.10 ± 16.82
HI CLBP (n = 5)	60.13[a,b] ± 14.92	61.25[a,b] ± 17.97	12.32[a] ± 4.41	11.64[a] ± 3.31	36.48 ± 12.88

**** Means ± SD, Same letter indicates significance differences***
† Lumbar ROM measured with double inclinometer
SLR = Straight leg raise; hamstring flexibility
Thomas Test = Hip flexor length
ROM = Range of motion

Strength results for the three groups are shown in Table 4.23. MANOVA demonstrated significant differences among the groups for trunk extension strength ($p = 0.03$). Tukey's post hoc indicated that the control group was significantly stronger

in trunk extension than the high CLBP group ($p = 0.05$). In addition, MANOVA detected significant differences among the groups in abdominal strength. The mean double leg lowering score in the control group was significantly lower (i.e., better strength) than the high CLBP group ($p = 0.002$).

Repositioning Accuracy

Repositioning measures (total range of motion, baseline neutral and mean absolute repositioning error) were recorded in both standing and seated positions. The results of the MANOVA indicated that the three groups were not significantly different standing TROM, standing neutral or standing repositioning. In addition, no significant differences were found in the seated repositioning measures. Means and standard deviations for the standing and seated repositioning measures are presented in Tables 4.24 and 4.25, respectively.

Table 4.23. Strength Measures of Controls, Low CLBP, and High CLBP*

	Strength					
	Hip Flexion†		Hip Extension†		Trunk Ext†	Trunk Flex (°)
	Right	Left	Right	Left		
Control (n = 10)	4.90 [a] ± 0.32	4.80 ± 0.42	4.90 ± 0.32	4.90 ± 0.32	4.90 [a] ± 0.32	41.68 [a] ± 16.73
LO CLBP (n = 4)	5.00 [b] ± 0.00	5.00 ± 0.00	5.00 ± 0.00	5.00 ± 0.00	4.50 ± 0.58	56.49 ± 14.27
HI CLBP (n = 5)	4.40 [a,b] ± 0.55	4.60 ± 0.55	4.60 ± 0.55	4.80 ± 0.45	4.00 [a] ± 0.71	78.73 [a] ± 15.50

** Means ±SD, Same letter indicates significance differences*
† Manual Muscle Testing (MMT)
Trunk Ext = Trunk Extension
Trunk Flex = Abdominal strength tested via double leg lowering

Table 4.24. Standing Measures of Total Range of Motion, Baseline Neutral and Repositioning Error for Controls, Low CLBP, High CLBP*

	TROM (°)	Baseline Neutral Position (°)	Mean Absolute RE (°)
Control (n = 10)	31.69 ± 15.70	2.95 ± 2.74	2.02 ± 0.71
LO CLBP (n = 4)	27.81 ± 21.67	3.07 ± 1.14	2.03 ± 1.27
HI CLBP (n = 5)	19.51 ± 14.17	2.12 ± 3.69	1.95 ± 0.98

** Means ± SD*
TROM = Total Range of Motion in Standing
RE = Mean Absolute Repositioning Error

Table 4.25. Seated Measures of Total Range of Motion, Baseline Neutral and Repositioning Error for Controls, Low CLBP, and High CLBP*

	TROM (°)	Baseline Neutral Position (°)	Mean Absolute RE (°)
Control (n = 10)	36.78 ± 17.80	10.70 ± 9.71	4.47 ± 3.24
LO CLBP (n = 4)	41.15 ± 18.58	17.63 ± 20.22	4.21 ± 3.90
HI CLBP (n = 5)	26.98 ± 8.83	13.52 ± 8.58	3.32 ± 1.08

** Means ± SD, ** $p < 0.05$*
TROM = Total Range of Motion in Seated Position
RE = Mean Absolute Repositioning Error

CHAPTER FIVE

DISCUSSION AND SUMMARY

The primary purpose of the study was to compare the ability of individuals with chronic low back pain (CLBP) and healthy controls to reposition their pelvis into a neutral position from the standing and seated positions. The second purpose of the study was to examine the relationships between performance on tests related to low back function, proprioception, and other selected variables.

The protocol in this study involved a single training session to introduce the participants to the neutral spine concept and teach them how to find their neutral position. The neutral spine training progressed from a supine position to a standing position. Within the same session, baseline neutral was measured with an electronic goniometer (elgon). Following the baseline measurement, the participants attempted to replicate their neutral position. The sequence was performed in standing and seated positions.

Neutral spine is the primary component of stabilization training[78, 100]. The objective of stabilization training is to provide sufficient spinal stability to enable one to match the demands of opposing forces in ADLs (e.g., changes in spinal posture, static, and dynamic loads)[84]. Stabilization resulting from pelvic control and muscular bracing can reduce cumulative microtrauma to the lumbar spine.

There is no particular lumbar spine position that is best for all individuals; thus the process of determining the neutral spine posture must be individualized[78, 100]. The neutral spine position is defined differently for healthy individuals and for those who suffer from LBP. In healthy individuals, neutral spine is defined as a position or range of positions of least physical stress on the spine between the extreme end ranges of pelvic range of motion[78, 120]. The neutral spine position for individuals with LBP is described as a pain free and stable position or range of positions[78].

Stabilization requires adequate flexibility and strength, as well as motor coordination. It also involves the ability to recognize the neutral position and maintain this position in order to protect the motion segments from potential injury or re-injury. Proprioceptive feedback plays an important role in the conscious and unconscious awareness of trunk posture. As previously mentioned the components of trunk proprioception are believed to diminish in individuals with LBP; however, there is limited research to support this contention. Nevertheless, proprioceptive deficits have been associated with an increased number of low back injuries[87], which may impair motor control, leading to functional instability[113]. Another important component of proprioception is the ability to acknowledge the changes in joint position and to reposition the joint accurately.

In this investigation, the ability to recognize the neutral position and re-attain this position was tested in a group of individuals with LBP and in a group of healthy control subjects. The results will be discussed within the context of the type of data collected.

Demographic Information

It was important to this study to keep the mean age of both groups similar to capture individuals most likely to experience CLBP and to control for age-related effects of proprioception. In this study, both groups were similar with regards to age, height, weight, and torso length. When the CLBP group was divided into low and high CLBP, the high group was the oldest of the groups. It has been shown that the incidence of LBP increases consistently with age in females. In males, the highest rates are found at 40 years of age and do not show a continuing increase with age as is seen in females. It is possible that the gender differences are due to the increased risk of osteoporosis in women as they become older[88]. Because, age-related changes in proprioception have been documented in studies investigating knee joint repositioning[52, 103], age could be an important factor from this perspective too.

Anthropometric

The estimated body fat percentage, based on measurements with a skinfold caliper and using the sum of three sites, was significantly higher in the CLBP group than in the control group in this study. On average, individuals with CLBP were approximately eight percent higher in body fat percentage than the controls. The CLBP group also had a slightly higher body mass index than the control group; however, this difference was not statistically significant. When the CLBP group was divided into two sub groups, estimated body fat and body mass index paralleled increases in ODQ scores; however, the differences were not statistically significant. Nevertheless, it is in

agreement with the contention that LBP is found more frequently in obese individuals[88].

Self-Reported Information

Physical Activity

The CLBP and control groups did not statistically differ in the number of minutes per week spent performing physical activity. When the CLBP group was divided into high (ODQ > 10) and low (ODQ < 10) groups, the high group reported 124 minutes per week of physical activity, whereas the control and low CLBP reported over 200 minutes of physical activity per week. Although, Cady, Bischoff, O'Connell et al.[19] concluded that physical fitness and conditioning have significant preventative effects on back injuries and LBP, it is possible that the lower physical activity level in the CLBP group may be due to either limitation or difficulty in participation because of the CLBP[88].

Oswestry Low Back Pain Disability Questionnaire (ODQ)

According to the ODQ scoring, this group of CLBP individuals demonstrated minimal to moderate disability (x=23.78%). Fairbank et al.[28] contended that persons with minimal disability may have difficulty with sitting postures and that those with moderate disability experience pain with sitting, lifting and standing. When the CLBP group was divided into two subgroups, the average ODQ scores reported by the low

CLBP and high CLBP groups were 4% and 39.6%, respectively. Table 5.1 contains the disability categories based on the interpretation of ODQ scores[28].

Flexibility

Flexible Curve

The lordotic curve was measured with a flexible ruler in relaxed standing and then after following neutral spine instruction. The flexible curve measure of the lordotic curve demonstrated that (1) the lumbar lordosis measures were significantly reduced with neutral spine posture within each group but not between the groups and (2) subjects could change their lordotic curve from relaxed standing. The CLBP group was slightly more lordotic in relaxed standing and decreased their lordosis

Table 5.1. Interpretation of Oswestry Disability Questionnaire Scores

Disability	Percentage	Description
Minimal	0-20%	Can cope with most ADLs; Usually no treatment indicated; Some patients may have difficulty with sitting
Moderate	20-40%	Experiences more pain and problems with sitting, lifting and standing; typically managed conservatively
Severe	40-60%	Pain is primary problem; Often have difficulty with personal care, travel, social life, etc.
Crippled	60-80%	Back pain affects all aspects of life
Bed-Bound	80-100%	Either bed-bound or report exaggerated symptoms.

** Fairbanks et al (1980)*

approximately 7°. When the CLBP group was divided into two subgroups, the lordosis in relaxed standing increased as the disability increased. Both the control group and high CLBP group reduced their lordosis with neutral positioning (3° and 6°, respectively); the low CLBP group increased their lordosis by 7°.

These results are consistent with previous research investigating the neutral spine posture. Levine and Whittle[63] demonstrated that pelvic tilt could be voluntarily manipulated to reduce the lordotic curve. Saal[98] contended that a neutral spine reduced lumbar lordosis, and when combined with muscular co-contraction, could reduce repetitive microtrauma on the lumbar spine structures. The strength and stability of the spine is increased through the maintenance of a small lordotic curve. The participants in this study were able to maintain some degree of lordosis in their neutral spine posture.

Lower Extremity Flexibility

The CLBP group demonstrated decreased hamstring flexibility (SLR) and greater hip flexor tightness (Thomas Test) compared to the controls; however the results were not significant. The CLBP group also demonstrated greater asymmetry in their flexibility scores than did the control group. The control and low CLBP groups demonstrated similar hamstring and hip flexor range of motion (ROM) scores; both groups demonstrated statistically greater hamstring ROM than the high CLBP group. The control group also demonstrated statistically greater hip flexor ROM than the high CLBP group.

The lack of hip and low back flexibility is often seen with the onset of LBP and has been used as a risk indicator for LBP[11, 88]. The hip muscles along with the muscles of the back, help control pelvic tilt through active and passive restraints[81].

Lumbar Range of Motion (ROM)

Lumbar ROM was similar in the CLBP group and in the control group. Although, the high CLBP group had less lumbar ROM than both the control and low CLBP group, this difference was not statistically significant. Reduced spinal motion, particularly flexion, has been demonstrated in most subjects with LBP[88].

Strength

Although, there were no significant differences between groups in hip flexion and hip extension strength, there were statistically significant differences between groups in trunk extension strength and trunk flexion strength. The CLBP had statistically significant weaker trunk extension strength (4.22) than the control group (4.90) as measured manually by the investigator using the techniques described by Kendall and McCreary[54]. When the CLBP group was sub-divided, the control subjects demonstrated significantly greater trunk extension strength than the high CLBP group. In general, both the CLBP group and control group demonstrated better than average trunk extensor strength in clinical terms.

The CLBP group demonstrated significantly weaker abdominal strength than the control group as indicated by a higher double leg lowering score. The control group

lowered their legs 27° more than the CLBP group. When the CLBP group was sub-divided, the control subjects demonstrated significantly greater trunk flexor strength than the high CLBP group. Youdas et al.[127] found that LBP sufferers demonstrated less abdominal strength on the double-leg lowering test than healthy adults. A decrease in abdominal muscle strength has been identified as a risk indicator for LBP[88]; moreover, abdominal strength has been suggested as being a foundation of the stabilization program[98].

Repositioning Accuracy

The reposition error score in standing was 1.99° for the CLBP group and 2.02° for the control group. In the seated position, the CLBP group reposition error was 3.72° and that of the control group was 4.47°. When the CLBP group was divided into two sub-groups, the high CLBP group demonstrated more accurate repositioning in the standing and seated postures compared to the control group and low CLBP group. The results did not support the primary hypothesis that individuals with CLBP are less able to reproduce their neutral spine position accurately in standing and seated positions than healthy individuals. It was also hypothesized that the magnitude of repositioning error would be smaller in the seated position in both groups as compared to standing due to increased proprioceptive input from the contact with the chair. Overall, for all subjects, the mean absolute repositioning error was greater in a seated position than in standing; therefore, this hypothesis also was not demonstrated in this study. However, when

actual raw repositioning values were used in the analyses, there were no differences between the standing and seated postures.

Gill and Callahan[38] found significant differences between LBP patients and a pain-free group in the ability to reposition the trunk in standing. However, in that study LBP patients were 10 years older than the controls, and since the controls were physiotherapists they might be expected to be more active and educated on proprioceptive rehabilitation than the experimental group.

The findings of Newcomer et al.[79] were similar to those in the present investigation in that they too reported no significant differences between trunk repositioning error in subjects with CLBP and controls. Their CLBP subjects were able to reposition within 2.1° of the target position in standing, whereas the controls repositioned within 2.5° of the target position. In the present investigation repositioning error in standing was 1.99° for the CLBP group and 2.02° for the control group. The subject groups were similar in age (39.1 and 39.3 years, respectively); however, in the Newcomer et al.[79] study, their controls had no history of LBP lasting more than three months and they were free from LBP for at least a year[79]. In the current study the control subjects did not have any history of LBP. Furthermore, the target positions and definitions of neutral posture in their study were different from the present study; therefore any other comparisons are difficult.

Undershooting and Overshooting

It was hypothesized that individuals with CLBP would overshoot their neutral position because of proprioceptive deficits. The results in the present investigation did not fully support that hypothesis. In this study, the CLBP group tended to undershoot in neutral standing (36.7%) and to overshoot in neutral sitting (42.4%). However, in both conditions, there was no particular bias toward undershooting and overshooting in the CLBP group. This could be due to the range given to define neutral spine; it was ±1° of their baseline neutral. There has been some evidence that individuals with LBP have a tendency to overestimate target positions[56]. Lam and colleagues[56] found that LBP patients overshot the target position more frequently (79%) than controls (50%).

Considerations Concerning Accuracy of Repositioning

ODQ Scores

The lack of significant differences in repositioning accuracy in the current study populations may be partially explained by the minimal LBP dysfunction demonstrated in the CLBP group. In other words, it is possible that their LBP disability was not enough to alter the afferent input, for the majority of the participants in this study reported that their low back disability did not interfere with occupational responsibilities and ADLs. The CLBP participants in this study exhibited a wide range of disability (2%-68%) with respect to the ODQ scores. When the CLBP group was sub-divided into two groups, the differences in the scores were more pronounced; the ODQ score for the low CLBP was 4% and the high CLBP group was 39.6%,

The disability categories as presented in Table 5.1, indicate differences in functional limitations based on the specific category. If initial inclusion criteria for the current investigation would have paralleled the aforementioned categories, and subjects representing those categories found, this may have resulted in a more homogenous CLBP groups. The placement of subjects into pain categories may eliminate the need for specific diagnoses, since it is difficult to determine an exact diagnosis in patients with LBP due to its multifactorial etiology[120].

Neutral Spine Position

As discussed previously, the neutral spine position is a subjective measure; therefore, baseline neutral position measures were recorded for each participant. The repositioning accuracy scores were the calculated difference between the baseline position and the repositioning attempt. To the author's knowledge, this is the first investigation that used the neutral spine position of the subject as the target position. Furthermore, this is the only study that has investigated pelvic positioning per se. Other studies have selected criterion positions in which the subjects attempted to replicate the position selected by the investigators or have investigated gross movements (i.e., trunk flexion).

Sensory Input

In this investigation proprioception was considered as the prime factor that enabled subjects to reposition accurately. However, there may have been other afferent input that provided the individuals with clues to their positions. In the current study the

subjects were tested with their eyes open; this protocol allows visual input to be a factor in the ability to position the pelvis. Some studies have controlled for visual input by blindfolding their subjects[14, 56, 67, 79]. However, Newcomer et al.[79] found no significant difference in repositioning accuracy attributable to eye condition (eyes open or closed) in their group of subjects; therefore, allowing vision in this current investigation provided for a more functional testing protocol.

It is also possible that additional sensory input was provided to the subjects via vestibular, cutaneous, and lower extremity mechanoreceptor pathways, thus masking proprioceptive deficits in the trunk. The individuals were tested standing without immobilization of their legs because it was desirable to test the individuals in a functional position. However, this testing position can provide subjects with vestibular as well as afferent input from the lower extremities that could influence performance. It is unknown how much immobilization can be used to eliminate extra sensory input (i.e., vestibular, mechanoreceptive) and still make the testing functional.

It has been suggested that accuracy of repositioning may be influenced by the availability of cutaneous mechanoreceptive feedback either directly or indirectly from contact with the supporting surface (e.g., sitting in a chair)[49]. However, in the current study, there were significant differences between the standing and seated conditions, and subjects repositioned into their neutral position more accurately in the standing position than in the seated position. The subjects in both groups demonstrated more TROM in the sitting position than in the standing position. The magnitude in repositioning error may be a result of a greater ROM. Further studies are needed to clarify the amount of extra sensory input that the different mechanisms provide.

Matching or repositioning tasks have been used in most other investigations. It is possible that the task of repositioning into neutral posture in this study did not challenge the proprioceptive system sufficiently[79]. Because, repositioning tasks place position sense under conscious control, it could be argued that these tasks are inappropriate since proprioceptive responses usually occur subconsciously[38]

It is possible that certain aspects of proprioception could be enhanced by CLBP, there was a trend for lower repositioning error in the CLBP group in both the standing and seated positions than in the control group. This is further supported by the performance of a CLBP sub-group; the high CLBP group demonstrated better repositioning accuracy in the standing and seated postures than did the control group and low CLBP group. Some recent research suggests that there is an increase in the number and sensitivity of mechanoreceptors in individuals with CLBP[95, 126]. It is also possible that pain provided afferent feedback in the CLBP group that offset differences in repositioning error between it and the control group. It is possible that persons with poor repositioning accuracy are predisposed to development of LBP, but as LBP becomes chronic, a decrease in repositioning error occurs as a compensatory adaptation technique. Prospective studies would be helpful to determine whether subjects with healthy backs who have higher repositioning error are predisposed to the development of LBP.

In the current study, the CLBP group was divided into high and low CLBP based on the ODQ. With a small number of individuals in each group, there were no significant differences demonstrated in either standing or seated repositioning accuracy. In both standing and seated, the high CLBP group demonstrated better repositioning

accuracy than the control or low CLBP groups. Interestingly, the high CLBP also demonstrated the smallest degree of TROM in both standing and seated positions. Further investigation, perhaps using the ODQ index to divide subjects in to levels of disability, could provide more information concerning repositioning accuracy.

Instrumentation Constraints

The lack of significant differences between the groups could also be a result of the instrumentation used in this study. It is possible the technique of measurement may not have been sensitive enough to detect between group differences in repositioning accuracy in the standing and seated positions. This is the only repositioning study found that has used the electronic goniometer to indirectly measure proprioception via repositioning accuracy. The elgon has been shown to produce comparable results to measures obtained with an inclinometer and flexicurve[13]; moreover, the repositioning results were similar to those reported in previous studies[14, 67, 79]. The reliability of the elgon in this study was high (ICC = 0.97). Variance in position sense can be due to differences in the repositioning task, posture, plane of movement, and instrument.

Correlations

A secondary purpose of the present investigation was to examine the inter-relationships between low back pain, repositioning accuracy and physical measurements. Spearman rank correlations were performed to investigate the relationships between low back pain, repositioning accuracy and physical

measurements. The Oswestry Low Back Pain Disability Index (ODQ) was used as the measure of CLBP. Repositioning measures included TROM, neutral, and repositioning error for both standing and seated positions. Other measures were divided into anthropometric, flexibility, and strength categories.

Relationships between CLBP and Repositioning Measures

The results demonstrated no significant relationships between CLBP and repositioning measures in the standing and the seated positions in the CLBP group. The relationships were low, ranging from -.087 to -.591. The results suggest that level of CLBP did not affect an individual's total lumbar range of motion, their neutral position, or their ability to reposition the spine into their neutral position. These results are consistent those of Newcomer et al[79]. These investigators found no significant correlation between low back pain (determined from the visual analog scale) and repositioning accuracy.

Relationships between CLBP and Other Physical Measures (Anthropometric, Flexibility and Strength)

No relationships were found between LBP and any of the anthropometric measures or physical activity for the CLBP group. Anthropometric data are somewhat conflicting, but in general indicate there is no strong correlation between height, weight, body type and CLBP[88].

There were significant relationships between hamstring length, hip flexor length, and CLBP. These relationships indicated that individuals who reported more

LBP had less flexibility. Physical findings such as reduced flexibility (as noted in the administration of test) are usually associated with CLBP disability[32].

The results indicated that individuals who reported more CLBP had significantly weaker abdominal muscle strength as demonstrated by the double-leg lowering test. In the current study, the CLBP group demonstrated an average double leg lowering score was 68.85° and the control group's score was 41.68°. Reduced strength of the flexor and extensor supportive musculature is associated with CLBP. Youdas et al.[127] found that LBP sufferers also demonstrated less abdominal strength on the double-leg lowering test than healthy adults. Furthermore, the odds-ratio of having CLBP is increased if the score on the double-leg lowering test exceeds 50° for men and 60° for women[127].

Relationships between Repositioning Measures (Standing and Seated) and Other Physical Measures (Anthropometric, Flexibility and Strength)

In general, all correlation in this category were low to moderate with very few of the relationships demonstrating statistical or clinical significance. In standing, there were no statistically significant relationships between repositioning measures and anthropometric measures for the CLBP group or control group. In the seated position, statistical significance was demonstrated in TROM and estimated body fat percentage and body mass index; indicating higher the body fat percentage or body mass index the less total range of motion the individuals had in a seated position. This suggests that individuals with a higher percentage of body fat may be prone to sitting positions in the end-ranges of lumbar ROM, making them susceptible to the onset of LBP.

In standing and seated positions, there appears to be a relationship between flexibility and TROM for individuals with CLBP. In healthy individuals, there also appears to be a relationship between flexibility and TROM in standing but not in a seated position. Furthermore, it appears there are inconsistent relationships between strength measures and repositioning measures in standing and seated positions in LBP or healthy individuals. The CLBP subjects in this study followed the typical patterns if risk indicators of LBP.

Summary

Although the results did not demonstrate significant differences in repositioning accuracy between CLBP and controls, it is still recommended that further study on proprioception and LBP should be performed. The best method of measuring proprioception/repositioning accuracy still needs to be established. In addition, inclusion criteria could be established to parallel the interpretation of the Oswestry Low Back Pain Disability Index. This may produce homogenous CLBP groups and allow for the detection of differences between groups if they exist.

Future studies examining whether proprioception is worsened or improved are important because of the implications in rehabilitation. If proprioceptive deficits exist, then proprioception retraining should be performed, as has been done in the peripheral joints. However, if proprioception is improved, perhaps an unlikely scenario, it may already suggest that LBP subjects have already developed compensatory strategies in attempts to prevent painful and potentially harmful conditions.

Limitations of the Study

The study was limited as follows:

1. Visual, vestibular and somatosensory input, although controlled for to a certain extent, were present in the investigation.
2. The electronic goniometer may not have been sensitive enough tot detect changes in pelvic position.
3. The division of subject groups was based on the Oswestry Low Back Pain Disability Index did not discriminate into two distinct disability levels.
4. The neutral spine posture is an individualized posture, therefore its criteria are difficult to ascertain.

REFERENCES

1. Gray's Anatomy. P. L. Williams, L. H. Bannister, M. M. Berry, et al., eds. 38th ed. New York: Churchill Livingstone; 1995.

2. Aaron, G. W. The use of stabilization training in the rehabilitation of the athlete. *Sports Physical Therapy Section Home Study Course* 1 - 24, 1996.

3. Alexander, M. J. L. Biomechanical aspects of lumbar spine injuries in athletes: A review. *Canadian Journal of Applied Sport Sciences* 10:1 - 19, 1985.

4. Amonoo-Kuofi, H. S. The density of muscle spindles in the medial, intermediate and lateral columns of human intrinsic postvertebral muscles. *Journal of Anatomy* 136:509-519, 1983.

5. Andersson, G. B. Epidemiological features of chronic low-back pain. *Lancet* 354:581-585, 1999.

6. Andersson, G. B. J., and J. W. Frymoyer. Treatment of the acutely injured worker. In:. *Occupational Low Back Pain,* M. H. Pope, G. B. J. Andersson, J. W. Frymoyer, et al., eds: C.V. Mosby; 1991.

7. Aspden, R. M. Intra-abdominal pressure and its role in spinal mechanics. *Journal of Biomechanics* 2:168 - 172, 1987.

8. Barrack, R. L., H. B. Skinner, and S. L. Buckley. Proprioception in the anterior cruciate deficient knee. *American Journal of Sports Medicine* 17:1-6, 1989.

9. Barrack, R. L., H. B. Skinner, and S. D. Cook. Proprioception of the knee joint. Paradoxical effect of training. *American Journal of Physical Medicine* 63:175-181, 1984.

10. Barrett, D. S. Proprioception and function after anterior cruciate reconstruction. *Journal of Bone and Joint Surgery [Br]* 73:833-837, 1991.

11. Biering-Sorensen, F., C. E. Thomsen, and J. Hilden. Risk indicators for low back trouble. *Scandinavian Journal of Rehabilitation Medicine* 21:151 - 157, 1989.

12. Bogduk, N., and J. E. Macintosh. The applied anatomy of the thoracolumbar fascia. *Spine* 9:164 - 170, 1984.

13. Boocock, M. G., J. A. Jackson, A. K. Burton, and K. M. Tillotson. Continuous measurement of lumbar posture using flexible electrogoniometers. *Ergonomics* 37:175-185, 1994.

14. Brumagne, S., R. Lysens, and A. Spaepen. Lumbosacral position sense during pelvic tilting in men and women without low back pain: test development and reliability assessment. *Journal of Orthopaedic and Sports Physical Therapy* 29:345-351, 1999.

15. Brumagne, S., R. Lysens, and A. Spaepen. Lumbosacral repositioning accuracy in standing posture: a combined electrogoniometric and videographic evaluation [In Process Citation]. *Clinical Biomechanics (Bristol, Avon)* 14:361-363, 1999.

16. Brumagne, S., R. Lysens, S. Swinnen, and S. Verschueren. Effect of paraspinal muscle vibration on position sense of the lumbosacral spine. *Spine* 24:1328-1331, 1999.

17. Bullock-Saxton, J. E., V. Janda, and M. I. Bullock. Reflex activation of gluteal muscles in walking. An approach to restoration of muscle function for patients with low-back pain. *Spine* 18:704-708, 1993.

18. Byl, N., and P. Sinnott. Variations in balance and body sway in middle-aged adults: Subjects with healthy backs compares with subjects with low back dysfunction. *Spine* 16:325-330, 1991.

19. Cady, L. D., D. P. Bischoff, E. R. O'Connell, P. C. Thomas, and J. H. Allan. Strength and fitness and susequent back injuries in firefighters. *Journal of Occupational Medicine* 21:269-272, 1979.

20. Caraffa, A., G. Cerulli, M. Projetti, G. Aisa, and A. Rizzo. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee Surgery, Sports Traumatolology, Arthroscopy* 4:19-21, 1996.

21. Cholewicki, J., and S. M. McGill. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. *Clinical Biomechanics* 11:1 - 15, 1995.

22. Cholewicki, J., S. M. McGill, and R. W. Norman. Lumbar spine loads during the lifting of extremely heavy weights. *Medicine and Science in Sports and Exercise* 23:1179 - 1186, 1991.

23. Corrigan, J. P., W. F. Cashman, and M. P. Brady. Proprioception in the cruciate deficient knee. *Journal of Bone and Joint Surgery [Br]* 74:247-250, 1992.

24. Cresswell, A. G., and A. Thorstensson. Changes in intra-abdominal pressure, trunk muscle activation and force during isokinetic lifting and lowering. *European Journal of Applied Physiology* 68:315 - 321, 1994.

25. Day, J. W., G. L. Smidt, and T. Lehmann. Effect of pelvic tilt on standing posture. *Physical Therapy* 64:510-516, 1984.

26. Deyo, R. A., and Y. J. Tsui-Wu. Descriptive epidemiology of low-back pain and its related medical care in the United States. *Spine* 12:264-268, 1987.

27. Donelson, R. The McKenzie approach to evaluating and treating low back pain. *Orthopedic Review* 19:681-686, 1990.

28. Fairbank, J. C., J. Couper, J. B. Davies, and J. P. O'Brien. The Oswestry low back pain disability questionnaire. *Physiotherapy* 66:271-273, 1980.

29. Fairweather, M. M., and B. Sidaway. Ideokinetic imagery as a postural development technique. *Research Quarterly for Exercise and Sport* 64:385 - 392, 1993.

30. Farwood, D. Dynamic lumbar stabilization training. 1998.

31. Fel'dman, A. G., and M. L. Latash. Interaction of afferent and efferent signals underlying joint position sense: Empirical and theoretical approaches. *Journal of Motor Behavior* 14:174-193, 1982.

32. Frymoyer, J. W., and W. Cats-Baril. Predictors of low back pain disability. *Clinical Orthopaedics and Related Research* 221:89 - 96, 1987.

33. Frymoyer, J. W., and W. L. Cats-Baril. An overview of the incidences and costs of low back pain. *Orthopaedic Clinics of North America* 22:263-271, 1991.

34. Frymoyer, J. W., and S. L. Gordon. Research perspectives in low-back pain. Report of a 1988 workshop. *Spine* 14:1384-1390, 1989.

35. Gajdosik, R. L., C. R. Albert, and J. J. Mitman. Influence of hamstring length on the standing position and flexion range of motion of the pelvic angle, lumbar angle, and thoracic angle. *Journal of Orthopaedic and Sports Physical Therapy* 20:213-219, 1994.

36. Gamboian, N. The use of somatic training to improve pelvic tilt and lumbar lordosis alignment during quiet stance and dynamic dance movement. In: *Department of Exercise and Movement Science.*: Univeristy of Oregon; 1997.

37. Garn, S. N., and R. A. Newton. Kinesthetic awareness in subjects with multiple ankle sprains. *Physical Therapy* 68:1667-1671, 1988.

38. Gill, K. P., and M. J. Callaghan. The measurement of lumbar proprioception in individuals with and without low back pain. *Spine* 23:371-377, 1998.

39. Glencross, D., and E. Thornton. Position sense following joint injury. *Journal of Sports Medicine and Physical Fitness* 21:23-27, 1981.

40. Goldie, P. A., O. M. Evans, and T. M. Bach. Postural control following inversion injuries of the ankle. *Archives of Physical Medicine and Rehabilitation* 75:969-975, 1994.

41. Gracovetsky, S. The Spinal Engine. . New York: Springer-Verlag Wien; 1988:505.

42. Gracovetsky, S., H. Farfan, and C. Helleur. The abdominal mechanism. *Spine* 10:317 - 324, 1985.

43. Granata, K., and W. Marras. The influence of trunk muscle coactivity on dynamic spinal loading. *Spine* 20:86-92, 1995.

44. Gronblad, M., M. Hupli, and P. Wennerstrand. Intercorrelation and test-retest reliability of the pain disability index (PDI) and the Oswestry disability questionnaire (ODQ) and their correlation with pain intensity in low back pain patients. *Clinical Journal of Pain* 9:189-195, 1993.

45. Hart, D., L., and S. J. Rose. Reliability of a noninvasive method for measuring the lumbar curve. *The Journal of Orthopaedic and Sports Physical Therapy* 8:180 -184, 1986.

46. Hodges, P. W., and C. A. Richardson. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. *Spine* 21:2640-2650, 1996.

47. Jackson, A. S., and M. L. Pollock. Generalized equations for predicting body density of men. *British Journal of Nutrition* 40:497-504, 1978.

48. Jackson, A. S., M. L. Pollock, and A. Ward. Generalized equations for predicting body density of women. *Medicine and Science in Sports and Exercise* 12:175-181, 1980.

49. Jakobs, T., J. A. Miller, and A. B. Schultz. Trunk position sense in the frontal plane. *Experimental Neurology* 90:129-138, 1985.

50. Jenkins, E. M., and D. G. Borenstein. Exercise for the low back pain patient. *Baillieres Clinical Rheumatology* 8:191-197, 1994.

51. Johannsen, F., L. Remvig, P. Kryger, et al. Exercises for chronic low back pain: a clinical trial. *Journal of Orthopaedic and Sports Physical Therapy* 22:52-59, 1995.

52. Kaplan, F. S., J. E. Nixon, M. Reitz, L. Rindfleish, and J. Tucker. Age-related changes in proprioception and sensation of joint position. *Acta Orthopaedica Scandinavica* 56:72-74, 1985.

53. Keeley, J., T. G. Mayer, R. Cox, R. J. Gatchel, J. SMith, and V. Mooney. Quantification of lumbar function. Part 5: Reliability of range-of-motion measures in the sagittal plane and an in vivo torso rotation measurement technique. *Spine* 11:31 - 35, 1986.

54. Kendall, F. P., and E. K. McCreary. Muscles, Testing and Function. . Baltimore: Williams and Wilkins; 1983.

55. Kishino, N. D., T. G. Mayer, R. J. Gatchel, et al. Quantification of lumbar function. Part 4: Isometric and isokinetic lifting simulation in normal subjects and low-back dysfunction patients. *Spine* 10:921 - 927, 1985.

56. Lam, S. S., G. Jull, and J. Treleaven. Lumbar spine kinesthesia in patients with low back pain *Journal of Orthopaedic and Sports Physical Therapy* 29:294-299, 1999.

57. LaPlante, M. Data on disability from the National Health Interview Survey, 1983-1985. InfoUse Report. . Washington, D.C: National Institute on Disability and Rehabilitation Research; 1988.

58. Laskowski, E. R., K. Newcomer-Aney, and J. Smith. Refining rehabilitation with proprioception training: Expediting return to play. *Physician and Sportsmedicine* 25:89-90;92;95;97-100, 1997.

59. Leboeuf-Yde, C. Body weight and low back pain. A systematic literature review of 56 journal articles reporting on 65 epidemiologic studies. *Spine* 25:226-237, 2000.

60. Lephart, S. M., M. S. Kocher, F. H. Fu, P. A. Borsa, and C. D. Harner. Proprioception following anterior cruciate ligament reconstruction. *Journal of Sport Rehabilitation* 1:188-196, 1992.

61. Lephart, S. M., D. M. Pincivero, J. L. Giraldo, and F. H. Fu. The role of proprioception in the management and rehabilitation of athletic injuries. *American Journal of Sports Medicine* 25:130-137, 1997.

62. Lephart, S. M., D. M. Pincivero, and S. L. Rozzi. Proprioception of the ankle and knee. *Sports Medicine* 25:149-155, 1998.

63. Levine, D., and M. W. Whittle. The effects of pelvic movement on lumbar lordosis in the standing position. *Journal of Orthopaedic and Sports Physical Therapy* 24:130-135, 1996.

64. Levine, D. F. Dynamic relationships between lumbar lordosis, pelvic tilt, and abdominal muscle performance. In: *Exercise Science Unit*. Knoxville: The University of Tennessee; 1994:94.

65. Lovell, F. W., J. M. Rothstein, and W. J. Personius. Reliability of clinical measurements of lumbar lordosis taken with a flexible rule. *Physical Therapy* 69:96-105, 1989.

66. Macintosh, J. E., N. Bogduk, and S. Gracovetsky. The biomechanics of the thoracolumbar fascia. *Clinical Biomechanics* 2:79 - 83, 1987.

67. Maffey-Ward, L., G. Jull, and L. Wellington. Toward a clinical test of lumbar spine kinesthesia. *Journal of Orthopaedic and Sports Physical Therapy* 24:354-358, 1996.

68. Marras, W. S., and G. A. Mirka. A comprehensive evaluation of trunk response to asymmetric trunk motion. *Spine* 17:318-326, 1992.

69. Marras, W. S., and G. A. Mirka. Electromyographic studies of the lumbar trunk musculature during the generation of low-level trunk acceleration. *Journal of Orthopedic Research* 11:811-817, 1993.

70. Mayer, T. G., S. S. Smith, G. Kondraske, R. J. Gatchel, T. W. Carmichael, and V. Mooney. Quantification of lumbar function. Part 3: Preliminary data on isokinetic torso rotation testing with myoelectric spectral analysis in normal and low-back pain subjects. *Spine* 10:912-920, 1985.

71. Mayer, T. G., A. F. Tencer, S. Kristoferson, and V. Mooney. Use of noninvasive techniques for quantification of spinal range-of-motion in normal subjects and chronic low-back dysfunction patients. *Spine* 9:588 - 595, 1984.

72. McCloskey, D. I. Kinesthetic sensibility. *Physiology Review* 58:763-820, 1978.

73. McGill, S. M. Electromyographic activity of the abdominal and low back musculature during the generation of isometric and dynamic axial trunk torque: Implications for lumbar mechanics. *Journal of Orthopaedic Research* 9:91 - 103, 1991.

74. McGlashen, K., J. A. Ashton-Miller, M. Green, and A. B. Schultz. Trunk positioning accuracy in the frontal and sagittal planes. *Journal of Orthopaedic Research* 9:576-583, 1991.

75. McKenzie, R. The lumbar Spine: Mechanical Diagnosis and Therapy. . Waikonee, New Zealand: Spine Publications, Ltd; 1990.

76. McLain, R. F. Mechanoreceptor endings in human cervical facet joints. *Spine* 19:495-501, 1994.

77. McLain, R. F., and J. G. Pickar. Mechanoreceptor endings in human thoracic and lumbar facet joints. *Spine* 23:168-173, 1998.

78. Morgan, D. Concepts in functional training and postural stabilization for the low-back injured. *Top Acute Care Trauma Rehabilitation* 2:8 - 17, 1988.

79. Newcomer, K., E. R. Laskowski, B. Yu, D. R. Larson, and K. N. An. Repositioning error in low back pain. Comparing trunk repositioning error in subjects with chronic low back pain and control subjects. *Spine* 25:245-250, 2000.

80. Nies, N., and P. L. Sinnott. Variations in balance and body sway in middle-aged adults. Subjects with healthy backs compared with subjects with low-back dysfunction. *Spine* 16:325-330, 1991.

81. Norris, C. M. Abdominal muscle training in sport. *British Journal of Sports Medicine* 27:19 - 27, 1993.

82. O'Sullivan, P. B., G. D. Phyty, L. T. Twomey, and G. T. Allison. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. *Spine* 22:2959-2967, 1997.

83. O'Sullivan, P. B., L. Twomey, and G. T. Allison. Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. *Journal of Orthopaedic and Sports Physical Therapy* 27:114-124, 1998.

84. Panjabi, M. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. *Journal of Spinal Disorders* 5:383 - 389, 1992.

85. Paquet, N., F. Malouin, C. L. Richards, J. P. Dionne, and F. Comeau. Validity and reliability of a new electrogoniometer for the measurement of sagittal dorsolumbar movements. *Spine* 16:516-519, 1991.

86. Paris, S. V. Anatomy as related to function and pain. *Orthopaedic Clinics of North America* 14:475 - 489, 1983.

87. Parkhurst, T. M., and C. N. Burnett. Injury and proprioception in the lower back. *Journal of Orthopaedic and Sports Physical Therapy* 19:282-295, 1994.

88. Pope, M. H. Risk indicators in low back pain. *Annals of Medicine* 21:387-392, 1989.

89. Porterfield, J. A., and C. DeRosa. Mechanical Low Back Pain. Perspectives in Functional Anatomy. . Second ed. Philadelphia: W.B. Saunders Company; 1998.

90. Revel, M. Rehabilitation of low back pain patients. A review. *Review of Rhumatology England Ed* 62:35-44, 1995.

91. Richardson, C., G. Jull, P. Hodges, and J. Hides. Therapeutic Exercise for Spinal Segmental Stabilization in Low Back Pain. Scientific Basis and Clinical Approach. . Edinburgh, United Kingdom: Churchill Livingstone; 1999:191.

92. Richardson, C., G. Jull, R. Toppenberg, and M. Comerford. Techniques for active lumbar stabilisation for spinal protection: A pilot study. *Australian Journal of Physiotherapy* 38:105 - 112, 1992.

93. Richardson, C., R. Toppenberg, and G. Jull. An initial evaluation of eight abdominal exercises for their ability to provide stabilisation for the lumbar spine. *Australian Journal of Physiotherapy* 36:6 - 11, 1990.

94. Risberg, M. A., B. D. Beynnon, G. D. Peura, and B. S. Uh. Proprioception after anterior cruciate ligament reconstruction with and without bracing. *Knee Surgery, Sports Traumatology, and Arthroscopy* 7:303-309, 1999.

95. Roberts, S., S. M. Eisenstein, J. Menage, E. H. Evans, and I. K. Ashton. Mechanoreceptors in intervertebral discs. Morphology, distribution, and neuropeptides [see comments]. *Spine* 20:2645-2651, 1995.

96. Robison, R. The new back school prescription: stabilization training. Part I. *Occupational Medicine* 7:17-31, 1992.

97. Saal, J. A. Dynamic muscular stabilization in the nonoperative treatment of lumbar pain syndromes. *Orthopaedic Review* 19:691 - 700, 1990.

98. Saal, J. A. The new back school prescription: stabilization training part II. *Occupational Medicine* 7:33 - 42, 1992.

99. Saal, J. A., and J. S. Saal. Nonoperative treatment of herniated lumbar intervertebral disc with radiculopathy. An outcome study. *Spine* 14:431 - 436, 1989.

100. SanFranciscoSpineInstitute. Dynamic lumbar stabilization program. In: *The Program*. San Francisco: San Francisco Spine Institute; 1989:35.

101. Schutte, M. J., and L. T. Happel. Joint innervation in joint injury. *Clinics in Sports Medicine* 9:511-517, 1990.

102. Shiple, B. J., and N. A. DiNubile. Treating Low Back Pain: Exercise knowns and unknowns. *Physician and Sportsmedicine* 25:51-52, 61-62, 65-66, 1997.

103. Skinner, H. B., R. L. Barrack, and S. D. Cook. Age-related decline in proprioception. *Clinical Orthopedics* 208-211, 1984.

104. Smidt, G. L., and P. R. Blanpied. Analysis of strength tests and resistive exercises commonly used for low back disorders. *Spine* 12:1025 - 1034, 1987.

105. Solomonow, M., B. H. Zhou, R. V. Baratta, Y. Lu, and M. Harris. Biomechanics of increased exposure to lumbar injury caused by cyclic loading: Part 1. Loss of reflexive muscular stabilization. *Spine* 24:2426-2434, 1999.

106. Swinkles, A., and P. Dolan. Spinal position sense is independent of the magnitude of movement. *Spine* 25:98-104; discussion 105, 2000.

107. Taimela, S., M. Kankaanpaa, and S. Luoto. The effect of lumbar fatigue on the ability to sense a change in lumbar position. A controlled study. *Spine* 24:1322-1327, 1999.

108. Taylor, J. L., and D. I. McCloskey. Proprioceptive sensation in rotation of the trunk. *Experimental Brain Research* 81:413-416, 1990.

109. Thomas, C. L. Taber's Cylopedic Medical Dictionary. . 17 ed. Philadelphia: F.A. Davis Company; 1993:2590.

110. Tillotson, K. M., and A. K. Burton. Noninvasive measurement of lumbar sagittal mobility. *Spine* 16:29 - 33, 1991.

111. Triano, J., and G. Cramer. Patient information: Anatomy and biomechanics. In: *Conservative Care of Low Back Pain,* A. H. White, R. Anderson, eds. Baltimore: Williams and Wilkins; 1991,:45 - 57.

112. Tropp, H., C. Askling, and J. Gillquist. Prevention of ankle sprains. *American Journal of Sports Medicine* 13:259-262, 1984.

113. Tropp, H., J. Ekstrand, and J. Gillquist. Stabilometry in functional instability of the ankle and its value in predicting injury. *Medicine and Science in Sports and Exercise* 16:64-66, 1984.

114. Tropp, H., P. Odenrick, and J. Gillquist. Stabilometry recordings in functional and mechanical instability of the ankle joint. *International Journal of Sports Medince* 6:180-182, 1985.

115. Troup, J. D., T. K. Foreman, C. E. Baxter, and D. Brown. 1987 Volvo award in clinical sciences. The perception of back pain and the role of psychophysical tests of lifting capacity. *Spine* 12:645-657, 1987.

116. University, S. U. M. Functional Anatomy of the Back: Health Science Center at Syracuse; 1999.

117. Vleeming, A., A. L. Pool-Goudzwaard, R. Stoeckart, J. P. van Wingerden, and C. J. Snijders. The posterior layer of the thoracolumbar fascia. Its function in load transfer from spine to legs. *Spine* 20:753-758, 1995.

118. Waddell, G., D. Somerville, I. Henderson, and M. Newton. Objective clinical evaluation of physical impairment in chronic low back pain. *Spine* 17:617-628, 1992.

119. Walker, M. L., J. M. Rothstein, S. D. Finucane, and R. L. Lamb. Relationships between lumbar lordosis, pelvic tilt, and abdominal muscle performance. *Physical Therapy* 67:512-516, 1987.

120. White, A. H. Stabilization of the lumbar spine. In:. *Conservative Care of Low Back Pain,* A. H. White, R. Anderson, eds. Baltimore: Williams and Wilkins; 1991, 106 - 111.

121. Williams, P. C. Lesions of the lumbosacral spine. Part I. Acute traumatic destruction of the lumbosacral intervertebral disc. *Journal of Bone and Joint Surgery* 19:343-363, 1937.

122. Williams, P. C. Examination and conservative treatment for disc lesions of the lower spine. *Clinical Orthopedics* 5:28-40, 1955.

123. Wojtys, E. M., B. B. Wylie, and L. J. Huston. The effects of muscle fatigue on neuromuscular function and anterior tibial translation in healthy knees. *The American Journal of Sports Medicine* 24:615-621, 1996.

124. Wyke, B. Neurological mechanisms in spasticity: a brief review of some current concepts. *Physiotherapy* 62:316-319, 1976.

125. Yamashita, T., J. M. Cavanaugh, A. A. el-Bohy, T. V. Getchell, and A. I. King. Mechanosensitive afferent units in the lumbar facet joint. *Journal of Bone and Joint Surgery [Am]* 72:865-870, 1990.

126. Yamashita, T., Y. Minaki, I. Oota, K. Yokogushi, and S. Ishii. Mechanosensitive afferent units in the lumbar intervertebral disc and adjacent muscle. *Spine* 18:2252-2256, 1993.

127. Youdas, J. W., T. R. Garrett, K. S. Egan, and T. M. Therneau. Lumbar lordosis and pelvic inclination in adults with chronic low back pain. *Physical Therapy* 80:261-275, 2000.

128. Youdas, J. W., T. R. Garrett, S. Harmsen, V. J. Suman, and J. R. Carey. Lumbar lordosis and pelvic inclination of asymptomatic adults [see comments]. *Physical Therapy* 76:1066-1081, 1996.

129. Youdas, J. W., V. J. Suman, and T. R. Garrett. Reliability of measurements of lumbar spine sagittal mobility obtained with the flexible curve. *Journal of Orthopaedic and Sports Physical Therapy* 21:13-20, 1995.

APPENDICES

APPENDIX A – INFORMED CONSENT

INFORMED CONSENT STATEMENT

Accuracy of Pelvis Repositioning in Individuals With and Without Low Back Pain

The purpose of this study is to investigate the ability of individuals to reposition pelvic posture (proprioception) in standing and seated positions using an electronic measuring device called an electronic goniometer (elgon).

INFORMATION

You are invited to attend a single one-hour session of data collection. The test session will include measures of height and body weight, flexibility of the low back and lower extremities, strength of the low back and lower extremity, body fat with skinfold calipers, and low back position with an elgon. You will be asked the following:

To wear shorts and tank top for ease of measurement.
To avoid doing strenuous physical activity one day before the data collection.
To avoid eating 2 hours before the test session.
To complete a health history information sheet and a low back pain questionnaire.

Measurements of your body size and shape (height, body weight, trunk length, and skinfold thickness to estimate body fat) will be recorded at the beginning of the test session. You will perform a standard warm-up and stretching protocol consisting of five minutes of light activity on a stationary bike followed by five minutes of static stretching. Range of motion (ROM) and muscle strength assessments will be recorded for the trunk and lower extremities.

ROM tests

Trunk flexion: You will stand with weight distributed evenly. You will keep your hands on your hips, knees straight and bend forward as far as possible, as if you were going to touch your toes.
Trunk extension: You will stand with weight distributed evenly. You will keep your hands on your hips, knees straight and arch backward as far as possible.
Straight leg raise: You will lay on your back, keep your knees straight and relax your leg. Your leg will be lifted until you feel tension.
Hip flexor length: You will lay on your back with legs straight and arms folded across your chest. Your leg will be brought towards your chest while the measurement is being taken.

Manual muscle strength tests

Abdominal strength: You will lay on your back with your arms folded across your chest. Your legs will be raised to a start position. You will slowly lower your legs down to the table.
Back strength: You will lay on your stomach with your hands behind your neck. You will be asked to raise yourself off the table as high as you can. The investigator will push down on your back between your shoulder blades as you try to hold the position.
Hip flexor: You will sit with both legs over the table edge. You will lift your thigh off the table and hold that position while the investigator tries to push your leg back towards the table.
Hip extensor: You will lay on your stomach and lift your leg off the table and hold that position while the investigator tries to push your leg back towards the table.

You will be introduced to the neutral spine concept then asked to find your own neutral spine position. To find your neutral spine position, you will move your low back forward and backward until tension is felt at both positions. Your neutral spine position will be a comfortable position in between those two extreme ranges of motion. This is a position where your back tolerates forces best. Your neutral spine posture will be recorded in both seated and standing positions. After you find your neutral spine position, you will be asked to perform a series of movements, then find your neutral spine position again. The positions will be recorded using an elgon. You will be asked to perform ten trials of each condition (seated and standing).

RISKS

The risks of these tests are believed to be minimal. Residual muscle soreness may occur from the various muscle strength assessments, however, overall discomfort, if any, should be minimal. The principal investigator involved in this study has extensive experience in strength and functional testing. Proper warm-up and instruction in low back movement will be provided and individual techniques observed and corrected to minimize any potential risks and to ensure your safety during all testing.

BENEFITS

You will receive a comprehensive low back assessment that includes strength and flexibility tests. This may serve to identify specific strengths, or more importantly, weaknesses of the trunk and lower extremities, which may be predisposing factors to low back pain/injury. You will also receive the results from body fat measurements. Furthermore, proper instruction and demonstration in proper pelvic positioning techniques and low back injury prevention will be provided to you.

_____**Participant's initials**

CONFIDENTIALITY
Your information will remain confidential during and after the study. Your information will be coded numerically during analysis and in the written report. Only the investigator, faculty advisor and you will have access to your information and data. Data will be stored on hard disk of Biomechanics/Sports Medicine Lab computers during the study, and will be backed up onto floppy disks/zip cartridge and erased from the hard disk after the completion of the study. Subject information sheets and back up floppy disks/zip cartridge will be stored in a locked cabinet in the Biomechanics/Sports Medicine Lab in room 135, HPER building. Consent forms will be stored in a locked cabinet in the HPER building for three years past the end of the study then will be destroyed.

CONTACT
If you have questions at any time about the study or the procedures, you may contact Traci Haydu at (865) 974-2091 or Wendell Liemohn at (865) 974-5111. If you have questions about your rights as a subject, contact the Compliance Section of the Office of Research at (865) 974-3466.

PARTICIPATION
Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from this study at any time without penalty. If you withdraw from the study before data collection is completed, your data will be destroyed.

CONSENT
I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Participant's signature _____ Date _____

Investigator's signature _____ Date _____

Traci Haydu, MS
HPER Bldg., Rm 135 (974-2091)

Wendell Liemohn, PhD
HPER Bldg., Rm 327 (974-5111)

APPENDIX B – INFORMATION/MEDICAL HISTORY FORM

SUBJECT INFORMATION SHEET

Subject #_____
Age_____
Physical Activity (min/wk)_____

Height (cm)_____
Weight (kg)_____
Torso Length (cm)_____

Have you had any of the following:

	Yes	No
Inner ear infection	_____	_____
Head injury	_____	_____
Vestibular disorder (i.e., dizziness)	_____	_____
Lower extremity injury	_____	_____
Low back, chest or abdominal surgery	_____	_____
Balance, coordination training in the past 6 months	_____	_____

Have you had any of the following diagnosed spine conditions? Check all that apply.

_____ None
_____ Sciatica
_____ Chronic LBP
_____ Herniated disc
_____ Leg length inequality
_____ Scoliosis
_____ Spinal compression fracture
_____ Degenerative disc disease
_____ Lumbar contusion
_____ Lumbar muscle strain
_____ Sacroiliac dysfunction
_____ Facet injury
Other:_____

Body Composition Measurements

Female	Chest	Abdomen	Thigh	Sum/BF%
1st				
2nd				
3rd				
Average				

Female	Tricep	Suprailiac	Thigh	Sum/BF%
1st				
2nd				
3rd				
Average				

Flexibility (ROM in degrees)

LE	SLR	Thomas
1st		
2nd		
3rd		
Average		

Trunk (DI)	Flexion (upper)	Flexion (lower)	Extension (upper)	Extension (lower)
1st				
2nd				
3rd				
Average				

Strength	Kendall Rating (0-5)
Hip Flexion	
Hip Extension	
Trunk Flexion	
Trunk Extension	

Double Leg Lowering _____
_____
_____

APPENDIX C – OSWESTRY LOW BACK PAIN DISABILITY QUESTIONNAIRE

Subject # _____

OSWESTRY LOW BACK PAIN DISABILITY QUESTIONNAIRE

Please Read:
This questionnaire has been designed to provide information as to how your back pain has affected your ability to manage in everyday life. Please answer every section and mark in each section only the one box which applies to you. We realize you may consider that two of the statements in any one section relate to you, but please just mark the box which most closely describes your problem.

Section 1 – Pain Intensity
- ☐ I can tolerate the pain I have without having to use pain killers.
- ☐ The pain is bad but I mange without taking pain killers.
- ☐ Pain killers give complete relief from pain.
- ☐ Pain killers give moderate relief from pain.
- ☐ Pain killers give very little relief from pain.
- ☐ Pain killers have no effect on the pain and I do not use them.

Section 2 – Personal Care (Washing, Dressing, etc)
- ☐ I look after myself normally without causing extra pain.
- ☐ I look after myself normally but it causes extra pain.
- ☐ It is painful to look after myself and I am slow and careful.
- ☐ I need some help but manage most of my personal care.
- ☐ I need help every day in most aspects of self-care.
- ☐ I do not get dressed, wash with difficulty and stay in bed.

Section 3 – Lifting
- ☐ I can lift heavy weights without extra pain.
- ☐ I can lift heavy weights but it gives extra pain.
- ☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned eg on a table.
- ☐ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned.
- ☐ I can lift only very light weights.
- ☐ I cannot lift or carry anything at all.

Section 4 – Walking
- ☐ Pain does not prevent me from walking any distance.
- ☐ Pain prevents me from walking more than 1 mile.
- ☐ Pain prevents me from walking more than ½ mile.
- ☐ Pain prevents me from walking more than ¼ mile.
- ☐ I can only walk using a stick or crutches.
- ☐ I am in bed most of the time and have to crawl to the toilet.

Section 5 – Sitting
- ☐ I can sit any chair as long as I like.
- ☐ I can only sit in my favorite chair as long as I like.
- ☐ Pain prevents me sitting more than 1 hour.
- ☐ Pain prevents me sitting more than ½ hour.
- ☐ Pain prevents me sitting more than 10 minutes.
- ☐ Pain prevents me from sitting at all.

Section 6 – Standing
- ☐ I can stand as long as I want without extra pain.
- ☐ I can stand as long as I want but it gives me extra pain.
- ☐ Pain prevents me from standing for more than 1 hour.
- ☐ Pain prevents me from standing for more than 30 minutes.
- ☐ Pain prevents me from standing for more than 10 minutes.
- ☐ Pain prevents me from standing at all.

Section 7 – Sleeping
- ☐ Pain does not prevent me from sleeping well.
- ☐ I can sleep well only by using tablets.
- ☐ Even when I take tablets I have less than 6 hours sleep.
- ☐ Even when I take tablets I have less than 4 hours sleep.
- ☐ Even when I take tablets I have less than 2 hours sleep.
- ☐ Pain prevents me from sleeping at all.

Section 8 – Sex Life
- ☐ My sex life is normal and causes no extra pain.
- ☐ My sex life is normal but causes some extra pain.
- ☐ My sex life is nearly normal but is very painful.
- ☐ My sex life is severely restricted by pain.
- ☐ My sex life is nearly absent because of pain.
- ☐ Pain prevents any sex life at all.

Section 9 – Social Life
- ☐ My social life is normal and gives me no extra pain.
- ☐ My social life is normal but increases the degree of pain.
- ☐ Pain has no significant effect on my social life apart from limiting my more energetic interests, eg dancing, etc.
- ☐ Pain has restricted my social life and I do not go out as often.
- ☐ Pain has restricted my social life to my home.
- ☐ I have no social life because of pain.

Section 10 – Traveling
- ☐ I can travel anywhere without extra pain.
- ☐ I can travel anywhere but it gives me extra pain.
- ☐ Pain is bad but I manage journeys over two hours.
- ☐ Pain restricts me to journeys of less than one hour.
- ☐ Pain restricts me to short necessary journeys under 30 minutes.
- ☐ Pain prevents me from traveling except to the doctor or hospital

VITA

Traci L. Haydu was born in Toledo, Ohio on March 12, 1971. She attended public schools in Petersburg, Michigan and Toledo, Ohio. She graduated from Whitmer High School in Toledo, Ohio in 1989. In 1989, she entered Eastern Michigan University on an athletic scholarship for Varsity Softball. There she received a Bachelor of Science degree in 1994 with an emphasis in Sports Medicine. Upon graduation, she accepted a position as the Assistant Director at The Center for Sports Medicine and Fitness in Ypsilanti, Michigan. In August 1996, she entered the Human Performance and Sports Studies graduate program at the University of Tennessee, Knoxville to pursue a Master of Science degree. While there, she worked in the Employee Fitness Program at the University of Tennessee Medical Center and was a Graduate Teaching Associate in the Sport and Physical Activity Program. She received a Master of Science degree in Exercise Science-Kinesiology in 1999.

Following graduation, Traci remained at the University of Tennessee to pursue a Doctor of Philosophy degree in Education with an emphasis in Biomechanics-Exercise Science. She continued to teach in the Sport and Physical Activity program in addition to teaching in the Biomechanics-Sports Medicine Lab. She was also a research assistant in the Biomechanics-Sports Medicine Lab. She also worked as a occupational health and safety consultant for Lifetime Wellness Consultants and was adjunct faculty at Roane State Community College.