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Alterations in Active and Passive Behavior of Lower Back Tissues Following Six Sessions of High Velocity Low Amplitude Spinal Manipulative Therapy for Healthy Participants

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ALTERATIONS IN ACTIVE AND PASSIVE BEHAVIOR OF LOWER BACK TISSUES FOLLOWING SIX SESSIONS OF HIGH VELOCITY LOW AMPLTIUDE SPINAL MANIPULATIVE THEARPY FOR HEALTHY PARTICIPANTS

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
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ABSTRACT OF THESIS

ALTERATIONS IN ACTIVE AND PASSIVE BEHAVIOR OF LOWER BACK TISSUES FOLLOWING SIX SESSIONS OF HIGH VELOCITY LOW AMPLTIUDE SPINAL MANIPULATIVE THEARPY FOR HEALTHY PARTICIPANTS

Non-specific low back pain (LBP) is a major health problem affecting a substantial portion of the population. The current treatments offered for non-specific LBP are oftentimes unsuccessful because the acting mechanism(s) of most treatment options are unknown. Obtaining a better understanding about the acting mechanism behind existing treatment options is, therefore, essential for the improvement of non-specific LBP treatment and management. The objective of this study was to gain a more comprehensive understanding about the acting mechanism of high velocity low amplitude spinal manipulative therapy, specifically the impact that high velocity low amplitude spinal manipulative therapy may have on the active and passive spinal musculoskeletal stabilizing subsystems along with the resultant spinal stability for healthy participants. A pre-post intervention study design completed by six healthy participants was used to quantify changes in the above noted aspects of spinal stability using a series of tests performed both before and after six sessions of high velocity low amplitude spinal manipulative therapy. The tests included seated balancing tests, lower back range of motion tests, and stress relaxation test. The six sessions of high velocity low amplitude spinal manipulative therapy did not significantly affect any of the test measurements among our healthy participant group.

KEYWORDS: high velocity low amplitude spinal manipulative therapy, unstable seated balancing tests, lower back range of motion, stress relaxation

Emily Croft

February 28, 2016

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Chapter 1: Introduction

Low back pain (LBP) is a major socioeconomic issue affecting approximately 60-80% of the population during their lifetime. At any moment in time, an estimated 12-30% of adults are suffering from LBP [1]. The financial burden of LBP is also significant. The direct and indirect costs in the United States from LBP cases have been estimated in the range of 19.6 to 118.8 billion dollars annually [2]. There are two main obstacles with LBP treatment: 1.) the underlying source for the majority of LBP cases is unknown (i.e. non-specific LBP), and 2.) the acting mechanism(s) of most treatment options available for such non-specific LBP cases is unknown. The low success rate of treatments offered for non-specific LBP may in part be attributed to these two important obstacles [3].

Even though the underlying source of the majority of LBP cases is unknown, instability of the spine has been suggested to play an important part in the development of LBP [4][5]. Without a stabilizing system, the vertebral column would fail under an applied compressive load surpassing 20 N [6]. The spine is stabilized by a synergy between three subsystems of the spinal stabilizing system namely: the passive musculoskeletal subsystem, active musculoskeletal subsystem, and neural and feedback subsystem [7]. Vertebrae, intervertebral discs, ligaments, facet joints, and joint capsules make up the passive musculoskeletal subsystem. The muscles and tendons encompassing the vertebral column make up the active musculoskeletal subsystem. Force and motion transducers are positioned within the components of the passive and active musculoskeletal subsystems, and both the central nervous system and the force and motion transducers make up the neural and feedback subsystem. Spinal instability can be attributed to dysfunction in one or more of these subsystems [7]. Therefore, the study of treatment-induced changes in these spinal stabilizing subsystems may help verify whether a given treatment option alleviates LBP via improving spinal stability. Obtaining a better understanding about the acting mechanism of existing treatment options, for this project specifically spinal manipulative therapy (SMT), is essential for the improvement of LBP treatment and management.

An accepted treatment for LBP relief is SMT. There have been numerous studies conducted evaluating the efficacy of SMT as a treatment option for non-specific LBP,

and although treatment efficacy is still under debate, the general consensus is SMT is effective [8][9][10][11]. Nonetheless, previous studies have also shown that not all LBP patients positively respond to SMT [8][9]. Therefore, gaining more information about the mechanisms behind high velocity low amplitude (HVLA) SMT may potentially help identify responder patients to help increase treatment success rate. The basis of HVLA SMT is the application of a force directed onto a target joint [12]. The HVLA thrust causes physiological, biomechanical, and neuromuscular changes in the trunk and spinal column, and if successful, reestablishes the normal physiological motion and function of the target joint and reduces the level of pain perceived by LBP patients [12] [13][14] (see § 2.4). These changes occur in the components of the active and passive musculoskeletal subsystems, so it is likely that an improvement in the status of spinal stability following treatment may play a role in the effectiveness of this treatment for certain LBP patients. To test such a general hypothesis two important questions should be answered: 1) what, if any, is the impact of such treatment-induced changes in the lower back tissues on the active and passive mechanical behavior of the lower back tissues and 2) if changes occur, how will these changes in the active and passive mechanical behavior of lower back tissues affect spinal stability? Answering the above two questions may help gain a better understanding about the acting mechanism of HVLA SMT.

The objective of the present study was to address the questions proposed in the previous paragraph. More specifically, to gain a more comprehensive understanding about the acting mechanism of SMT, the impact that HVLA SMT may have on the active and passive musculoskeletal stabilizing subsystems, and the resulting effect on spinal stability. This study was originally designed to include both LBP patients and healthy participants. Our original hypothesis was that compared to healthy participants, the LBP patients would demonstrate a greater improvement in the state of spinal stability. Due to various constraints, the scope of the present study was adjusted to include only healthy individuals, however, we still expected to see positive changes in the state of spinal stability. The investigation of SMT-induced changes in the state of stability among healthy individuals is expected to establish a baseline for future investigation wherein the beneficial effects of HVLA SMT can be evaluated for LBP patients.

Chapter 2: Background

2.1 Non-Specific Low Back Pain

"Pain localized between the 12th rib and the inferior gluteal folds, with or without leg pain" [1] is classified as LBP. The underlying cause of the LBP is only identified in approximately 5-10% of LBP cases, and these LBP cases are classified as specific LBP cases [1]. The underlying cause of the LBP for specific LBP cases include but are not limited to tumor, osteoporosis, infection, fracture, inflammatory disorder, radicular syndrome, or cauda equine syndrome [3]. A significant limitation for the diagnosis and treatment of the majority of LBP cases is that the underlying cause is unknown. This type of LBP is classified as non-specific LBP. Non-specific LBP is identified as a pain resulting from an unknown underlying source. There are a large number of treatments currently offered for non-specific LBP relief, but because the source of the majority of LBP cases is unknown, many of the treatments are relatively unsuccessful in relieving the pain [3].

2.2 Spinal Stability

Even though the underlying mechanism for most LBP cases is unknown, instability of the spine has been identified as a risk factor for the development of LBP [7]. A compressive load that is greater than 20 N would cause the vertebral column to buckle [6]. The vertebral column therefore requires a system to stabilize the column and prevent buckling under the 500-1000 N compressive loads experienced on a daily basis, as well as the loads experienced during more strenuous activities [15]. The vertebral column stabilizing system consists of three components: 1). passive musculoskeletal subsystem, 2). active musculoskeletal subsystem, and 3). neural and feedback subsystem. Although the three subsystems are separated for conceptual purposes, the subsystems work interdependently [7]. The passive musculoskeletal subsystem includes vertebrae, intervertebral discs, ligaments, and facet joints [7][15]. The passive musculoskeletal subsystem does not directly contribute to the stability of the vertebral column until the end range of motion of the spine. At this point, the passive musculoskeletal subsystem components generate reactive forces to inhibit motion of the spine. Before this point, the passive musculoskeletal subsystem components act as transducers to provide important

positional information necessary for the other two subsystems to function properly. The active musculoskeletal subsystem includes the muscles and tendons encompassing the vertebral column that generate the necessary forces to stabilize the vertebral column. The tendons and muscles also contain force transducers to provide information about the forces generated by the muscles. The neural subsystem transmits the transducer signals from the other two subsystems in order to provide the necessary stability forces, and then guides the active musculoskeletal subsystem to generate the forces needed to establish stability for the vertebral column [7]. Different experimental and computational methods have been used to study spinal stability [6][16][17][18][19][20][21]. The unstable seated balance test is one of the experimental methods currently used to study spinal stability [5].

2.3 Seated Balance Tests

Previous studies have investigated the postural control of participants suffering from neuromuscular disorders. During these studies, participants were instructed to maintain a quiet standing position on a force plate. The participant's center of pressure (CoP) movement (body sway) was measured by the force plate during the quiet standing position. Of these studies, several found that the participants suffering from LBP exhibited a lower level of postural control than the healthy participants. The underlying system of lumbar postural control cannot be understood entirely from studying a quiet standing posture because adjustments to posture can be accomplished through a combination of or individually by the ankle, knee, hip, and lumbar joints of the spine. While seated, the lumbar postural control is separated from the influence of the ankle, knee, and hip joints. Therefore, a surrogate method for studying postural control of the trunk was developed by studying a participant's body sway during seated balancing tasks on an unstable seat apparatus (wobble chair) [22]. This surrogate method has been connected to stability of the spine, and LBP patients have displayed a difference in body sway on the wobble chair when compared to healthy participants [5].

2.4 Spinal Manipulative Therapy

Americans are increasingly adopting manual therapies in addition to or in replacement of conventional medical care [23] [24] [25], particularly those suffering from back problems [23][26][27]. Of those manual therapies, SMT is a commonly used treatment for non-specific LBP. Although there are multiple forms of SMT, this study focused on the HVLA technique. The goals of HVLA SMT are the reestablishment of the normal physiological motion and function of the joint, reduction of pain, and the prevention of LBP reappearance [13][14]. The basis of HVLA SMT is the application of a force directed onto a target joint. This mechanical action results in deformations onto the spinal column and adjacent soft tissues [12]. During the SMT, a pre-load force is initially applied onto the target joint to move the joint to its passive end range of motion [9][12]. The actual HVLA treatment occurs when the clinician applies a high velocity, low amplitude thrust onto the targeted joint, which results in the targeted joint moving past the joint's passive end range of motion [12]. Although there is a limited amount of confirmed information about the underlying mechanisms of HVLA SMT, there are multiple theories available, some supported by research, about the biomechanical, physiological, and neuromuscular changes that occur as a result of HVLA SMT and their possible effect on relieving LBP symptoms.

Multiple studies have investigated the induced biomechanical changes occurring during HVLA SMT. Studies completed by Gal et al [28][29] used bone pins to investigate vertebral body movement at the targeted and neighboring joints in human cadavers throughout the HVLA SMT. The bone pins were implanted into three adjoining thoracic vertebral bodies, and the relative movement was calculated for the initial pre-load phase and HVLA thrust phase. The pre-load phase had considerable relative movement of all three vertebral bodies, and additional relative movement occurred for all three vertebral bodies throughout the HVLA thrust phase [12]. A study completed by Nathen et al [30] implanted pins within the spinous processes of the lumbar vertebrae to investigate the intervertebral displacement in the lumbar spine when an HVLA thrust is applied to the L2 spinous process. The maximum axial displacement generated was 1.62mm +/- 1.06 mm, the maximum shear displacement generated was 0.48 +/- 0.1 mm,

and the L3- L4 spinal motion segment rotation generated was 0.89 +/- 0.49˚. These studies support the idea that there is a displacement of the spinal motion segment during both the pre-load and thrust phase of the HVLA SMT [31].

One proposed reasoning for why HVLA SMT is an effective treatment for certain types of facet joint related LBP is HVLA SMT potentially breaks up adhesions that have formed on the facet joints. The premise behind this theory is that hypomobility of a facet joint results in the formation of adhesions on the joint, and these adhesions inhibit the joint's normal range of motion. The HVLA thrust is thought to cause a separation between the joint's articular surfaces, thereby breaking up adhesions and restoring the mobility of the joint. As a result, the physiological range of motion of the spinal motion segment is also restored [13]. A study completed by Cramer et al [32] confirmed the theory that the articular surfaces of the facet joints in the lumbar spine separate during the HVLA thrust phase of SMT for healthy participants. This theory has not been tested on participants suffering from LBP [13].

HVLA SMT has also been suggested to release trapped meniscoid. The idea behind this theory is that during lumbar spine flexion, the inferior articular process on the facet joint shifts up, which by default, moves the meniscoid. Upon extension of the joint, the inferior articular process and the meniscoid move toward their natural anatomical position. In some instances though, when the meniscoid attempts to return to the joint cavity, the meniscoid collides with the articular cartilage and buckles. This proposed buckling creates the formation of a lesion beneath the capsule. This space-filling lesion generates tension within the capsule. Since a large quantity of nociceptors are located within the facet joint capsules, the generated capsular tension may lead to pain and inhibition of movement. HVLA SMT is thought to open the joint and allow the meniscoid to return to its natural anatomical position, thereby reducing pain and restoring movement [33].

HVLA SMT has also been used to relieve symptoms of intervertebral disc related LBP. Using cadavers, Maigne et. al [34] observed that the internal pressure of an intervertebral disc changed during HVLA SMT. Upon the initial application of the HVLA thrust, the internal pressure of the disc increased as the two adjoining vertebral

bodies moved closer together. During the final portion of the HVLA thrust, the vertebral endplates separated, and the internal disc pressure decreased. After the HVLA thrust, the internal disc pressure quickly returned to its baseline value [34][35]. The alterations in internal pressure of the intervertebral disc during the HVLA SMT could potentially explain some of the observed clinical benefits in patients suffering intervertebral disk related LBP. One theory behind the disc related LBP relief is that a part of the nucleus pulposus becomes embedded within the annulus fibrosus. This leads to disc related LBP. This theory relies on the idea that the HVLA SMT could potentially return the embedded fragments back to the nucleus pulposus as a result of the pressure change during the HVLA thrust phase. This theory has yet to be confirmed or supported [35]. Another theory behind disc related LBP relief involves the stress concentrations that occur within an intervertebral disc. Adams et al [36] observed that under a sustained load, pressure peaks occur within the lumbar disc, and these pressure peaks occurred at the disc locations under the largest stress concentration. For this theory, the peaks in pressure are thought to stimulate the nerve endings located within the annulus fibrosus and endplates and cause pain. The change in internal pressure of the intervertebral discs during the HVLA thrust may lower the peak pressure amplitude, and as a result, lessen the disc related LBP. This theory still requires in vivo studies [35].

The biomechanical effects from an HVLA SMT are also thought to bring about changes in the signaling process of sensory neurons located within the paraspinal tissues. This theory arises from the idea that an HVLA thrust applied to the spinal motion segment creates a biomechanical overload. This overload may affect the signaling process of neurons sensitive to mechanical and chemical changes, and these alterations in sensory input may potentially impact reflex activity and pain processing [31].

HVLA SMT is thought to elicit a reflex response in the paraspinal muscles [31]. A study completed by Herzog et al [37] used surface electrodes on asymptomatic participants to investigate the paraspinal muscle reflex response at the location of the SMT. Following the application of the HVLA thrust, the electromyography (EMG) response from the paraspinal muscles was recorded within 50-200 milliseconds and ended after 100-400 milliseconds. No EMG activity was measured during the pre-load

phase of the treatment. Since no EMG activity was observed during the pre-load phase and the muscle activity lasted only 100-400 milliseconds, this suggests that the recorded response from the paraspinal muscles was a reflex response [12]. The muscle reflex response produced from the HVLA SMT may contribute to certain observed SMT clinical benefits, such as a decrease in either/both pain and muscle hypertonicity [37].

Alterations in pain processing has also been suggested as a possible outcome of SMT [31]. Glover et al [38] used LBP patients to study portions of the skin in the lumbar region sensitive to a pinprick (e.g. pinprick results in pain) to investigate the difference in pain sensitivity before and after SMT. Following the SMT, the area of skin sensitive to the pinprick decreased in the patients who received the SMT in comparison to the patients in the control group [31]. Terrett and Vernon [39] used electrical stimulation to investigate the changes in pain sensitivity of paraspinal tissues following SMT for thoracic back pain participants. A pain threshold was first determined. The threshold was the smallest amount of current needed to produce pain. 30 seconds after the SMT, the pain tolerance of the particpants increased significantly, and continued to increase for 9 ½ minutes. These studies suggest that the signaling process for nociceptors located within the paraspinal tissues may alter as a result of SMT [31].

2.5 Previous Studies of Spinal Stability Using the Unstable Seat Device

Multiple studies have investigated the state of stability of the spine through the use of an unstable seat device. Cholewicki et al [22] fabricated the initial unstable seat device to investigate postural control in the lumbar region of the spine while performing balancing tasks on an unstable seat.

Cholewicki et al [22] used his unstable seat device to establish a procedure to evaluate the lumbar postural control region during unstable sitting tasks for 11 healthy participants. For the unstable seat design, the chair was attached to the bottom of a polyester resin hemisphere. Changing the levels of difficulty of the balancing tasks was accomplished through the use of varying hemisphere diameters. The smaller the diameter of the hemisphere, the more difficult the task of maintaining an upright balanced posture (e.g. a smaller diameter sphere resulted in an increase in the instability of the seat). Four

levels of difficulty, 0 1 2 3, were used for the balancing tasks. A 0 level of difficulty was a flat surface, and the instability of the seat increased with each level. At the 1st, 2nd, and 3rd difficulty level, the participants first completed 1 minute of balance practice on the unstable seat before completing five seated balancing tests for each difficulty level. No practice trials were performed for the 0 difficulty level. For each of the five tests, the actual data collection did not begin until the participant had achieved a steady state condition with regards to balance control. Once steady state had been achieved, the participant continued to try and maintain a balanced position for an additional 7 seconds. Data was only collected during the 7 second balancing portion of the test. Random walk analysis and CoP summary statistics (RMS, MAX, and PATH) were calculated (see §3.5.3.1 for a description of RMS and PATH). MAX is the maximum distance that the CoP traveled during the balancing test. All the summary statistics were calculated in the anterior-posterior, medial-lateral, and radial directions. For the random walk analysis, a stabilogram was constructed from the five tests for each difficulty level. This stabilogram displayed two regions, the short-term region and long-term region. A straight line was fitted on both regions, and the slopes formed the diffusion coefficients D_s (short-term slope) and D_l (long-term slope). The point where the line transitions from the short-term region to the long-term region is the critical point (C_p). The exponential approximation for the short-term and long-term region formed the scaling exponents H_s (short-term region) and H_l (long-term region). All of the CoP summary statistics showed a significant increase as the level of difficulty of the balancing tasks increased. D_s and D_l generally displayed an increase in relation to an increase in the level of difficulty. H_s displayed a significant increase for difficulty levels 1-3 in comparison to the 0 difficulty level. The difficulty level had no effect on H_l. The CoP summary statistics and the short-term region D_s and H_s values displayed excellent repeatability. For the long-term region, D_l displayed only fair repeatability, and H_l displayed poor repeatability [22].

A study completed by Radebold et al [40] used Cholewicki's unstable seat design to examine the differences in lumbar postural control between 16 chronic LBP patients and 14 healthy participants. The LBP patients and healthy participants completed seated balancing trials using the same device and stability measures used in the study completed by Cholewicki et al [22]. The only difference between the two study protocols is the

particpants in this study completed the balancing tests for both eyes open and closed, otherwise the procedures used in the two studies were the same. For the healthy participants, 71% of the participants were successfully able to balance at the 3rd level of difficulty for the eyes closed position, and 100% of the participants successfully balanced at all four difficulty levels for the eyes open condition. For the chronic LBP patients, only 13% of the patients were successfully able to balance at the 3rd level of difficulty for the eyes closed condition, and only 69% of the patients were able to balance at the 3rd level of difficulty for the eyes open condition. The results suggest that LBP patients rely heavier on visual feedback than healthy participants. The LBP patients demonstrated larger values for the CoP summary statistics than the healthy participants. For the 1st and 2nd difficulty level, the LBP patients demonstrated significantly worse CoP summary statistics in the anterior-posterior direction than the healthy participants, and significantly worse CoP summary statistics in the medial-lateral direction at the 2nd difficulty level. The diffusion coefficients D_s (short-term region) and D_l (long-term region) were greater for the LBP patients, and the diffusion coefficients differences between the two groups grew as the level of difficulty increased. The scaling exponent H_s (short-term region) was larger in the healthy participants than the LBP patients, but both groups had an H_s value larger than 0.5. The scaling exponent H_l (long-term region) was not affected by either the level of difficulty, visual feedback, or whether the participant was healthy or suffering from chronic LBP. This study found that chronic LBP patients demonstrated larger body sway, and therefore worse lumbar postural control, than healthy participants when balancing on an unstable seat device [40].

A study completed by Dieën et al. [41] used Cholewicki's original unstable seat design. The study examined the various parameters used to quantify sway (CoP movement) during the balancing tasks for 331 participants in an attempt to identify the independent parameters of sway, the test-retest reliability, and the parameters of sway connected to loss of balance during the seated balancing tasks. The 331 participants were divided into 3 groups: 1.) current-LBP patients, 2.) participants who experienced LBP within the last year (recent-LBP), and 3.) healthy participants [42]. Each participant initially completed two minutes of practice trials before completing three 30 second seated balance tests. The polyester resin hemisphere diameter remained the same for all

three seated balance tests. Data recorded in the initial 5 seconds of the three seated balance tests was removed during analysis to prevent non-stationarity data from affecting the results. The test-retest reliability of the majority of the sway parameters was low, as well as largely intercorrelated (e.g. offering no unique information). H_s (short-term region scaling exponent) seemed to include unique information and displayed an adequate reliability. Parameters demonstrating a low test-retest reliability, as well as those deemed highly correlated, were removed from any more analysis. The remaining parameters were analyzed to determine the parameters related to loss of balance. Of the remaining parameters, only a low meanV (average CoP velocity) and a high D_s (short-term region diffusion coefficient) were significantly related to loss of balance during the seated balancing tasks when performing multivariate analysis. Meaning those participants who displayed a smaller meanV and a higher D_s were more likely to exhibit loss of balance during the balancing tests. None of the parameters displayed a relation to loss of balance when performing univariate analysis. The reason for the low reliability for the majority of the sway parameters could be attributed to the trail duration time, which was only 30 seconds. Therefore, a higher trial duration could result in a greater reliability for more of the parameters of sway [41].

The data collected in the Dieën et al. [41] study described above was also used to investigate how the sway parameters used to quantify lumbar postural control during seated balance tests altered between the three groups of participants [42]. The RMS in the anterior-posterior and medial-lateral directions, and the mean power frequency (MPF) were two of the sway parameters investigated in the study. The MPF was determined by calculating the frequency of the CoP displacements in the anterior-posterior and medial-lateral directions. Stabilogram diffusion analysis was also used to determine the diffusion coefficient D_s (short-term region). The recent LBP group demonstrated the lowest values for RMS in both directions, and the RMS values in the recent LBP group were significantly less than the healthy participants. For the MPF, the current LBP group demonstrated the lowest values of MPF in both directions. The LBP group MPF value was significantly less than the two other groups in the anterior-posterior direction and was significantly less than the recent LBP group in the medial-lateral direction. The healthy participants demonstrated the largest values of D_s in both directions, but a

significant difference between the healthy participants and the two other groups only occurred for the D_s value in the anterior-posterior direction. This study had the opposite finding of Radebold et al [40] with regards to differences in postural sway between LBP patients and healthy participants. The Radebold et al found that healthy participants demonstrated smaller RMS, PATH, and MAX values than LBP patients, whereas the current study found that healthy participants did not have the smallest RMS and MPF values in comparison with the current LBP group and recent LBP group. The two studies did have a difference with regards to the LBP patients. Radebold et al used chronic LBP patients, whereas Dieën et al used LBP patients with self-reported pain and no specifications with regards to the length of time of the current LBP group [42].

A study completed by Reeves et al [43] used Cholewicki's initial unstable seat design to investigate the connection between postural control and the stiffness of the trunk during balancing tasks on an unstable seat. A decrease in the passive stiffness of the trunk may occur following an injury. This loss may result in a stabilizing system less capable of handling perturbations. A potential approach to compensate for a weakened trunk passive stiffness is to increase the level of activation in the active musculoskeletal stabilizing subsystem, but an increase in the active musculoskeletal stabilizing subsystem would also increase the signal dependent noise (SDN). Increased activation requires the recruitment of extra motor units. This additional recruitment causes an increase in the development of internal noise in the system. This internal noise acts as an internal perturbation on the spine which could potentially degrade the active musculoskeletal stabilizing subsystem's performance in tasks needing exact motor control. Therefore, the primary objective of the Reeves et al study [43] was to investigate whether the performance in movements needing exact motor control was comprised when the stiffness of the spine increased, and if the performance was compromised, what was the reason for the degradation. The polyester resin hemisphere diameter remained the same throughout the balancing tasks. Four conditions were used on the unstable seat: control, belt, co-activation of trunk, and arm co-activation. For the belt task, the participants wore a lumbosacral brace to increase the level of passive stiffness in the trunk. For the co-activation of the trunk task, participants were instructed to increase the activation of the muscles in their trunk during the balancing task in order to increase the level of active

stiffness in the trunk. For the arm co-activation task, participants were instructed to make a fist and contract the muscles in their forearm during the balancing task. The arm co-activation task acted as a control to the co-activation of the trunk task. The control was used to investigate whether the balancing task performance was affected by the additional concentration needed to sustain an increased activation in the muscles. For each test, once steady state was reached, the participants continued to hold a balanced position for an additional 20 seconds. The CoP velocity calculated during the 20 second balancing period was the measure used to quantify postural control. The CoP velocity during the co-activation of trunk seated balancing task was significantly higher than the arm co-activation and control seated balancing task. The CoP velocity during the belt seated balancing task was significantly lower than the co-activation of trunk seated balancing task. Therefore, the study's original hypothesis, which stated that the postural control performance while balancing on an unstable seat would be comprised as the muscle activity of the trunk increased, was supported by the results. Since the degradation was only detected in the co-activation of trunk seated balancing task, this suggests that SDN was the likely source of the performance deterioration [43].

Other studies have made modifications to Cholewicki's initial unstable seat design, as well as the method used for studying postural control of the lumbar region. The primary modification made to the original unstable seat design was the use of springs instead of varying diameter hemispheres to change the difficulty of the seated balancing task. A master's thesis study completed by Lee [44] at Virginia Polytechnic Institute and State University appears to be the first study that used the modified unstable seat design (i.e. the wobble chair). This study used the wobble chair to determine the minimum duration of time required for the process to achieve stationarity status, as well as the intra/inter-session reliability of the measures of stability during the seated balancing tasks for twelve healthy participants. Stability was estimated from kinematic variability and nonlinear stability analysis. The balancing tasks were completed for three different levels of balancing assistance from springs: 100% ΔG, 75% ΔG, and 50% ΔG. The spring locations were calculated by multiplying the system potential energy by the balancing support condition (e.g. 1, 0.75, and 0.50) and dividing that value by the spring constant and finally, taking the square root of that value. Prior to the actual data collection, the

participants first completed practice seated balancing trials. Three practice trials were performed for the 100% and 75% balancing support conditions, and five practice trials were completed for the 50% balancing support condition. All practice trials were 60 seconds in duration. For the actual data collection, the seated balancing tasks at the 100%, 75% and 50% balancing support conditions were performed five times. All data collection trials were 60 seconds in duration. Across all balancing support conditions (100%, 75%, and 50%) and all directions (anterior-posterior, medial-lateral, and radial) a mean (standard deviation) time of 30.2 (11.8) seconds was found to be the minimum time required for the signal to reach process stationarity. For the kinetic data, the anterior-posterior direction required the largest amount of time for the signal to achieve process stationarity. For the anterior-posterior direction, the more difficult balancing tasks (e.g. 75% and 50% balancing support condition) required a minimum time between 30 and 43 seconds. The less difficult balancing task (100% balancing support condition) required a longer minimum time of 47 seconds. As such, using a time period greater than 47 seconds for data collection is an efficient time duration for all balancing support conditions in all directions to reach process stationarity. The kinematic variance measures for the majority of balancing support conditions showed good to excellent intra-session reliability. The 75% and 50% balancing support conditions had an intra-session reliability that was significantly more dependable than the 100% balancing support condition. The majority of the kinematic variance measures showed a poor to good inter-session reliability. The 100% balancing support condition demonstrated the worst inter-session reliability. For the nonlinear stability analysis calculated from the kinetic data, the stabilogram diffusion analysis short-term region scaling exponent (H_s), and the lyapunov exponent were found to be an excellent stability measure for intra-session reliability. For inter-session torso stability comparisons, H_s was found to be an excellent measure because the H_s value demonstrated the best inter-session reliability [44].

In an occupational environment, repeated lifting tasks have been identified as a risk factor for the development of LBP. Therefore, many companies are revising certain work tasks to be performed through pulling/pushing exertions in replacement of lifting. Lee [44] completed another study in his master's thesis that investigated how the state of spinal stability changed following pushing and pulling exertion tasks for 12 healthy

participants. Stability was estimated from the kinematic variability and nonlinear stability analyses of the CoP data. The kinematic variability measures used in analysis were RMS and EA, and the nonlinear stability analysis measures used were the stabilogram diffusion analysis short-term region scaling exponent (H_s) and the lyapunov exponent. While seated on the wobble chair, a horizontal force was applied to the participant's trunk at the level of T8. In order to sustain an upright seated balanced position on the wobble chair, the participant needed to apply either a trunk extension or trunk flexion moment. The applied moment (e.g. extension vs. flexion) depended on whether the horizontal force was directed anteriorly or posteriorly on the trunk. Three different force values were applied to the trunk (0N 40N and 80N). Elastic bands were used to produce the three different horizontal isotonic forces. The elastic band was connected to both a wall in the laboratory and the harness on the participant's chest. The horizontal force value changed by altering the elastic band tension. The participant completed seated balancing tests for the three force values on both the anterior and posterior side of the trunk. Prior to the actual data collection, the participant first completed five practice seated balancing trials for the given condition before completing five actual data collection trials. This protocol was used for all conditions. All practice and actual data collection trials were 60 seconds in duration. The kinematic variability and nonlinear stability analysis measures displayed a significant increase in relation to the level of the exertion force (0N 40N 80N). This increase in the stability measures showed that the application of a larger force value on the trunk resulted in a decrease in the state of stability. The flexion exertion balancing tasks (e.g. a posteriorly directed horizontal force) displayed a lower state of stability than the extension exertion balancing tasks (e.g. an anteriorly directed horizontal force). The flexion exertion balancing tasks demonstrated larger values of the kinematic variability measures (RMS and EA) than the extension exertion balancing tasks for the 40N and 80N force level conditions. For the nonlinear stability analysis measures, the Lyapunov exponent showed a significant increase during the flexion exertion balancing tasks than the extension exertion balancing task for the 40N force level condition. The short-term region scaling exponent, H_s, stability measure was not affected by the direction of the force. This study supported the hypothesis that the state of spinal stability decreases under the application of a larger extension/flexion force on the trunk, and flexion

exertions (pushing tasks) have a lower state of stability than extension exertions (pulling tasks) [44].

Whole body vibration (WBV) has also been identified as a risk factor for the development of LBP. A large quantity of individuals are exposed to WBV on a daily basis due to their occupation (e.g. truck drivers, delivery drivers, operators of construction equipment, etc…). A study by Slota et al [5] at Virginia Polytechnic Institute and State University used the wobble chair to study acute changes in trunk postural control following 30 minutes of WBV exposure for 21 healthy participants. Before the participants completed the actual data collection sessions, they first completed a calibration procedure to determine the location of the springs such that maintaining a balanced position on the wobble chair was challenging but not impossible. Initially, the location of the springs were positioned near a 100% balancing support condition (13 cm from the pivot point). The participant completed a seated balancing trial at this condition. After the initial seated balancing trial, the location of the springs was brought 1-2 cm closer to the pivot point, and the participant completed another seated balancing trial at the modified location of the springs. This procedure was continued until either the participant was unable to maintain a seated balanced position at the modified spring location or the seat range of motion continuously exceeded a 7˚ radial slant. For the first scenario, the location of the springs was then moved 0.5 cm away from the pivot point until seated balance was reestablished and the seat continuously exceeded a 7˚ radial slant. For the second scenario, the location of the springs remain unchanged. This calibrated spring location was used for the actual data collection trials, and the calibration procedure also acted as practice trails. The participants initially completed four 60 second seated balancing tests on the wobble chair before being exposed to 30 minutes of WBV. Following the WBV exposure, three additional seated balancing tests were completed. Kinematic variability and nonlinear stability analysis were used to quantify changes in the state of spinal stability pre and post WBV exposure. All of the nonlinear stability analysis and kinematic variability stability measures increased after WBV exposure. Increases in these stability measures supports the hypothesis that trunk postural control is degraded, which also implies a decrease in the state of spinal stability, immediately following WBV exposure [5].

A study completed by Tanaka et al [45] investigated the postural control system by exploring a different approach for changing the task difficulty levels. The Tanaka et al study introduced a new metric for quantifying stability called the threshold of stability (ToS). This new metric is based on the idea that kinematic variability will increase when the difficulty of the task increases. This increase results in the participant occupying a larger area of state space when trying to maintain a seated balanced position. Another effect of the task difficulty increasing is the area of state space available for the participant to explore and still be considered stable (e.g. the basin of stability) will decrease. When the kinematic variability moves past the basin of stability region, the system will begin to show behavior that is unstable. ToS is defined as "the maximum task difficulty in which stability can be maintained, and is found by increasing task difficulty until KV lies just within the boundary of the basin of stability" [45]. The study objective was to establish a method for the development of the ToS metric and determine the efficacy of the ToS metric as a stability measure for 8 asymptomatic participants. The study investigated the efficacy of the ToS method theoretically using an inverted pendulum mathematical model, and empirically using visual feedback conditions during seated balancing tasks on the wobble chair. The participants first completed the same calibration process as Lee [44] to determine the initial location of the springs. After calibration, the anterior-posterior spring was moved to the 80% ΔG balancing support condition and the medial-lateral spring was moved to the 100% ΔG balancing support condition. The medial-lateral springs location remained unchanged throughout the trials in order to isolate the movement to the sagittal plane, so modifications on spring location were only completed on the two anterior-posterior springs. The participant completed a seated balancing trial for the initial spring location. After the seated balancing trial, the location of the anterior-posterior springs was modified using three guidelines: 1.) If the participant managed to keep a seated balanced position that was within 4˚ of the wobble chair pivot point throughout the balancing task, the location of the anterior-posterior springs was adjusted such that the balancing support condition was lowered by 20% ΔG 2.) If the participant managed to keep a seated balanced position throughout the balancing task but not within 4˚ of the pivot point, the location of the anterior-posterior springs was adjusted such that the balancing support condition was lowered by 10% ΔG and finally

3.) If the participant was unable to balance on the wobble chair, this anterior-posterior spring location was considered to be the approximate ToS value. Once the approximate ToS value was determined, the location of the anterior-posterior springs was increased by 5%ΔG. If the participant was able to maintain a seated balanced position at the modified spring location, they would complete additional seated balancing trials at this given spring location. If the participant was unable to maintain a seated balanced position at the modified spring location, the location of the anterior-posterior springs was additionally increased by 5%ΔG. This was continued until the participant reached a spring location where they were able to maintain a seated balance position. Testing was finished, if after eight seated balancing tests for a given anterior-posterior spring location, the participant was able to maintain a seated balance position for more than half of the seated balancing tests. If the participant was unable to maintain a seated balance for more than half of the eight tests at a given spring condition, the location of the anterior-posterior springs was increased by 5%ΔG. This process continued until the participant reached a spring location where they were successfully able to maintain a balanced position in more than half of the eight seated balancing tests. This location of the springs was considered the ToS value. The participants completed the process described above for two conditions: 1.) eyes open and 2.) eyes closed. The ToS variable was found for both conditions. The study examined whether the ToS method was sensitive enough to detect differences between the two conditions since visual feedback has a major effect on tests investigating balance control. The study also used a mathematical model to investigate the theoretical premise behind the ToS method. The results of the study showed that the ToS method was sensitive enough to detect a significant difference in the ToS value between the two conditions (eyes open vs. closed), and the mathematical model supported the theoretical premise behind the ToS method [45].

2.6 Summary

The objective of the present study was to address two important questions: 1) what, if any, is the impact of HVLA SMT treatment-induced changes in the lower back tissues on components of the active and passive musculoskeletal stabilizing subsystems and 2) if these changes occur, how will the changes in the active and passive

musculoskeletal stabilizing subsystems affect spinal stability? It was hypothesized that changes in lower back tissues following SMT will improve the state of spinal stability of healthy individuals.

Lower back range of motion tests were used to evaluate the components in the active musculoskeletal stabilizing subsystem, and a stress relaxation test investigated the components in the passive musculoskeletal stabilizing subsystem. Seated balance tests on a wobble chair were used to empirically estimate the state of spinal stability. The seated balance tests also addressed the potential affect that the components of the passive and active musculoskeletal subsystems have on spinal stability, since both subsystems must work together to maintain a seated balanced position on the wobble chair.

Chapter 3: Methods

3.1 Participants

Six female healthy volunteers participated in this study after completing a consenting process approved by the University of Kentucky Institutional Review Board. To minimize the effects of individual, occupational, and lifestyle differences between the volunteers on our measures of lower back biomechanics, all participants were recruited to be between 22-45 years of age, with a BMI between 20-30 and a sedentary to recreationally active lifestyle. The participants needed to be healthy and free of LBP (i.e., experiencing a pain level in their lower back no greater than 1 on a 0 to 10 scale). Five of the participants had a pain rating of 0, and one participant had a pain rating of 1, which was due to muscle tightness from exercise. Mean (SD) age, height, and weight of participants were respectively 24.67 (1.75) years, 1.691 (0.091) m, and 69.173 (9.829) kg. Participants with a history of trunk or lower body surgery that might hinder their range of motion were excluded. Participant recruitment was done via study flyer distribution on the website of University of Kentucky Center for Clinical and Translational Science (CCTS).

3.2 Study Design

A pre versus post comparison study design was used to investigate the effects of HVLA SMT on spinal stability and on the active and passive musculoskeletal stabilizing subsystems. The study took place in the Human Musculoskeletal Biomechanics Laboratory (HMB lab) and the Charles T. Wethington Building at the University of Kentucky. All participants completed an initial data collection session followed by six sessions of HVLA SMT over an approximately three-week period. After receiving the six sessions of HVLA SMT, participants completed a second data collection session. During each data collection session, participants completed three sets of tests: 1.) seated balance tests, 2.) lower back range of motion tests, and 3.) stress relaxation test. The seated balance tests empirically measured the state of spinal stability. The lower back range of motion tests evaluated the components in the active musculoskeletal stabilizing subsystem, and the stress relaxation test investigated the components in the passive musculoskeletal stabilizing subsystem. Components of the passive and active

musculoskeletal stabilizing subsystems must work together to maintain a balanced position throughout the seated balancing tests. Each data collection session lasted approximately 2 ½ to 3 hours while each HVLA SMT lasted less than 10 minutes.

3.3 Consenting and Screening Process

When potential volunteers first initiated contact about their interest in the study, the eligibility criteria on the study's advertised flyer was verified (Appendix A.1). An electronic copy of the consent form was emailed to those volunteers who met the inclusion criteria. This consent form provided potential subjects an overview of the study and the study protocol (Appendix A.2). If the volunteer decided to move forward with the study upon reading the consent form, they were invited to the HMB lab for the consenting procedure. During this procedure, the principal investigator and the potential subject thoroughly went over the consent form, and the subject was provided the opportunity to ask any questions they had about the study. The volunteer was also shown the instrumentation and equipment used for data collection. After the consenting process was completed, and the participant decided to move forward with the study, the participant was asked to sign the consent form. A signed copy of the consent form was given to the participant upon their request.

The consented participant was then asked to complete a screening document that included verification of advertised criteria, personal information, and a psychosocial risk assessment (Appendix A.3). This screening document verified the participants eligibility based on the initial advertised criteria. Upon the completion of the screening draft, all eligible volunteers underwent a medical screening. For the musculoskeletal screening, a licensed chiropractor performed a standard physical examination on the participant. The physical examination included a range of motion evaluation, sensory evaluation, reflex evaluation, and motor evaluation, as well as blood pressure measurements, height, weight, and a level of pain rating based on a 0 to 10 scale (Appendix A.4). The chiropractor then reviewed the results of the physical examination, and a participant was excluded if the chiropractor determined the HVLA SMT could be harmful to the participant. Those participants who were deemed eligible for the study after the screening process were invited back to the HMB lab to complete the first data collection session.

3.4 Experimental Procedure

For the data collection session, the participant's blood pressure, oxygen saturation, and pain rating were initially measured and recorded. The participant then completed the tests in the following order: 1.) seated balancing tests, 2.) lower back range of motion tests, and 3.) stress relaxation test.

3.4.1 Seated Balancing Tests

3.4.1.1 Calibration Procedure

The wobble chair apparatus design (Fig. 3.1) is patterned on a previous wobble chair model developed at Virginia Polytechnic Institute and State University [5][44]. The seat is able to pivot in all directions as the result of a ball bearing located underneath the seat pan positioned at the center of the platform. Balancing assistance is provided by four springs located underneath the seat pan. Adjustments made to the location of the four springs (relative to the ball bearing) changed the amount of balancing assistance provided by the springs, and as a result, the level of difficulty of holding an upright balanced posture position. A force platform (AMTI, Watertown, MA) underneath the seat pan records the forces and moments (F_x F_y F_z M_x M_y M_z) during the balancing tests. An adjustable foot rest is attached to restrict movement of the lower limbs, and a seat belt is attached to the seat to restrain the pelvis during the balancing tests in order to isolate movement to the spine only. Before working with the wobble chair, the wobble chair needs to be calibrated to find the correct spring location for the balancing tests for each participant [5][44].

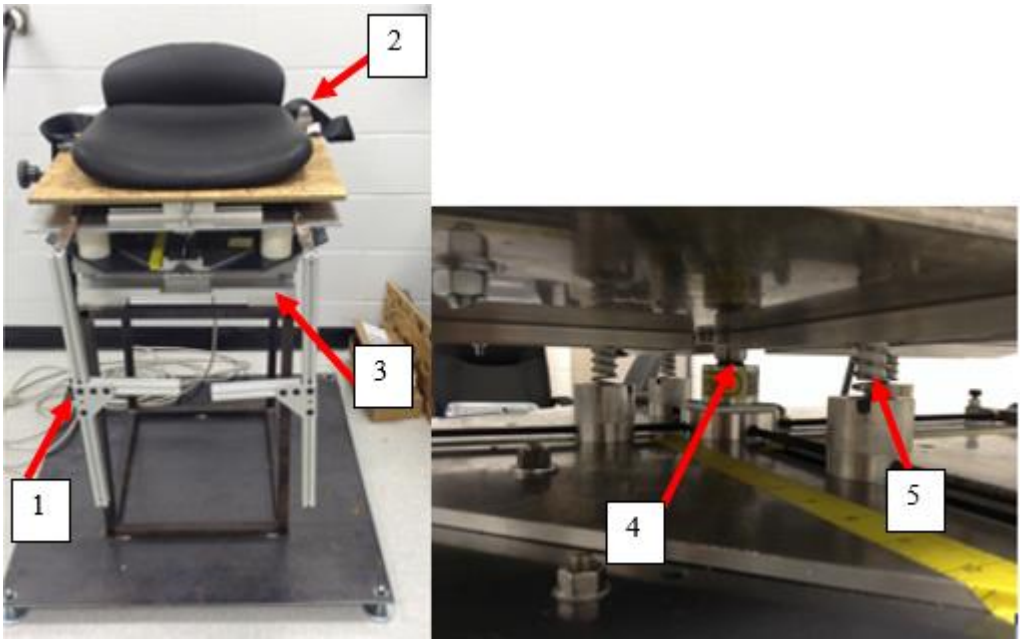


Figure 3.1: The Wobble Chair

The wobble chair design consists of five components: 1.) an adjustable foot rest, 2.) an attached seat belt, 3.) a force platform, 4.) a ball bearing, and 5.) four springs.

The location of the springs for each of the balancing tests was determined using the same method and equations developed by Lee [44] at the Virginia Polytechnic Institute and State University. During spring calibration, the participant's trunk, the chair, and the spring locations are fixed, so a free body diagram of a rigid body was used to calculate the location of the four springs. The participant's trunk and seat-pan are represented by a simplified single inverted pendulum. Since dynamic trunk motion is essential for maintaining a balanced position on the wobble chair, a moment equation can be derived about the ball joint.

$$Mgh\sin(\theta) - KdL\sin(\theta) = I\alpha \quad (1)$$

There is minimal seat movement during the balancing test, so a small angle assumption can be applied, and a steady state condition is assumed. Applying the small angle assumption, steady state condition, and after performing additional equation manipulations Eq. 1 can be modified and rewritten as

$$L = \sqrt{Mgh/K} \quad (2)$$

The spring constant K is a known variable (34.60 lbf/in). In order to determine the spring location, L, the system potential energy (Mgh) must first be calculated. The net moment change between the seat tilted at the 10˚ forward position and 10˚ backward position was used to calculate the system potential energy (Mgh). The net moment change is found from the force platform moment measurement at the two tilted positons. A removable backrest is used during the calibration process to ensure an upright trunk posture during the two tilted positions [44] (Fig. 3.2).

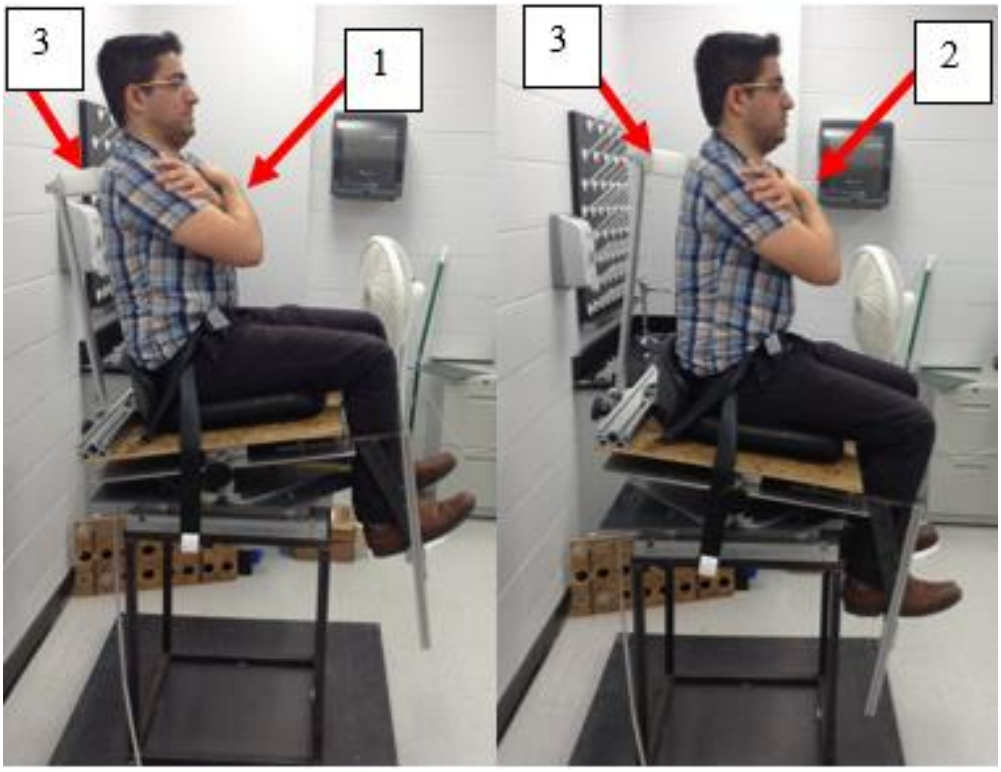


Figure 3.2: Wobble Chair Positions During Calibration
Two tilted positions were used during the spring calibration process: 1.) 10˚ backward tilted position and 2.) 10˚ forward tilted position. A removable backrest (3) kept the trunk upright at the two tilted positons during the calibration process.

Eq. 1 was used to calculate Mgh. The $KdL\sin(\theta)$ component of equation 1 represents the moment from the springs. For the calibration, the location of springs are moved adjacent to the pivot point (e.g. ball joint) making the distance between the pivot point and spring

location negligible. This component can therefore be ignored, which gives the following two equations for the two tilted positions:

$$Mgh\sin(10°) = M_1 \quad (3)$$

$$Mgh\sin(-10°) = M_2$$

Using Eq. 3, the Mgh (system potential energy) can be rewritten as

$$Mgh = \frac{M_1 - M_2}{\sin(10°) - \sin(-10°)} \quad (4)$$

The spring location, L, determined from equation 2 and 4, represents the location at which a full balance assistance (i.e., 100% support) is provided by the springs. This study examined the state of spinal stability at three different balancing support positions. The 100% balancing support position was found using equation 2. For all other balancing support positions, the balancing support condition percentage is multiplied by MGH. Therefore, the 100%, 75% and 50% balancing support position, L, are calculated as follows [44]:

$$L = \sqrt{Mgh/K}$$

$$L = \sqrt{Mgh * 0.75/K}$$

$$L = \sqrt{Mgh * 0.50/K}$$

3.4.1.2 Seated Balancing Tests

Before using the unstable seat device (wobble chair) for data collection, all participants first underwent a calibration process to determine the location of the springs at the 100%, 75%, and 50% balancing support conditions during the seated balance tests (see § 3.4.1.1). Upon completion of the calibration process, the participant completed the balancing tests in the following order: 100%, 75%, and 50% balancing support condition. The protocol used during the seated balancing tests was based off the protocol developed by Lee [44] at Virginia Polytechnic Institute and State University. Each seated balancing

test lasted 60 seconds during which, the participant tried to keep an upright trunk posture. Before the subject sat on the wobble chair, the location of the springs was adjusted to provide the desired level of support. Once the spring location was set, the participant sat on the wobble chair, and the attached seat belt was buckled to secure the participant onto the device, as well as to restrain movement of the pelvis during the balancing tests. The participant placed their feet on an attached foot stand. The role of the attached foot stand was to limit the amount of lower body movement during the balancing tests. The height of the foot stand was modified for every participant to achieve a 90 degree angle of the knee. The foot position was consistent for all subjects with both feet positioned directly against the vertical column of the foot rest. The participant's arms were crossed directly against the trunk during the balancing trials to prevent interference from the upper extremities (Fig. 3.3).

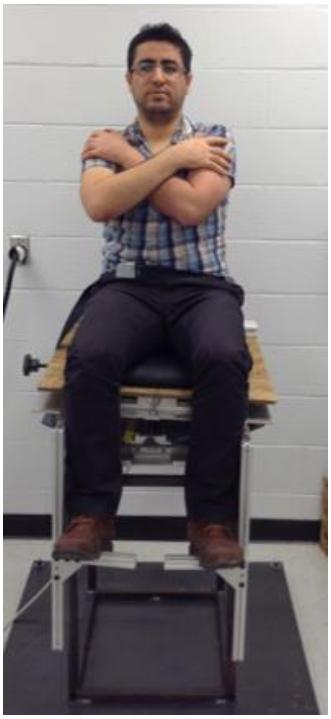


Figure 3.3: Position of Participant During the Seated Balancing Tests

For all of the balancing tests, the participant was instructed to attempt and maintain an upright balanced seated posture position on the wobble chair during the 60 second trial. For the 100% and 75% balancing support conditions, participants first

completed three practice trails, to prevent any learning effects, followed by five actual trials. For the 50% balancing support condition, participants completed five practice trials before completing the five actual data collecting trials. The force platform measured the the forces and moments (F_x, F_y, F_z, M_x, M_y, and M_z) during the balancing tests. Between every trial, both practice and actual, one minute rest was provided to limit mental and physical fatigue [44]. Upon completion of all balancing tests, participants were provided a 15 minute break to rest. During this time, the experimental set-up for the range of motion tests and stress-relaxation tests was prepared. During the break, the participant's blood pressure and oxygen saturation were measured and recorded.

3.4.2 Lower Back Range of Motion Tests

After the 15 minute break, the participant was instrumented with a tri-axial Inertial Motion Sensor (Xsens, Culver City, CA) system. This system used four Xsens accelerometers located at the level of the subject's sternum, pelvis, upper thigh, and ankle to measure the participant's upper and lower body motion during the lower back range of motion tests. Velcro straps where placed on the participant at the specified location, and each strap contained a clasp to hold an accelerometer. The accelerometer positions were as follows: 1.) For the ankle, the strap was placed on the participant's right leg above the ankle, with the clasp positioned on the lateral side 2.) For the upper thigh, the strap was placed on the participant's right thigh approximately halfway between the knee joint and the hip joint, with the clasp positioned on the lateral side 3.) For the pelvis, the strap was placed at the spinal level of S1, with the clasp positioned on the back in-line with the midline the trunk 4.) For the sternum, the strap was placed at the spinal level of T10, with the clasp positioned on the back in-line with the midline of the trunk. The distance between the ground and the top of each accelerometer clasp in neutral standing posture was measured to ensure the accelerometer locations during the second data collection session were in a placement similar to the first data collection session [46].

Every participant completed two range of motion tests while standing on a force platform (AMTI, Watertown, MA). The two range of motion tests were slow flexion/extension and fast flexion/extension. For the slow flexion/extension test, the participant initially held a quiet standing position on the force platform for five seconds.

After the five second holding period, the participant was instructed to slowly bend forward until they reached their comfortable maximum trunk flexed position. The participant held this flexed posture for five seconds, and then returned slowly to the original upright standing position. In total, the participant completed the procedure three consecutive times, with a five second holding period between each succession. A similar procedure was employed for the fast flexion/extension test. The difference between the two tests occurred after the initial five second holding position, the participant was instructed to bend forward and return to the original upright standing position as quickly as possible without holding the flexed posture position at the bottom. To ensure the five second holding period was consistent for the two lower back range of motion tests and participants, the researcher conducting the data collection session used a clock and counted the five second holding period out loud [46].

Upon completion of the two range of motion tests, the accelerometers and straps were removed from the participant.

3.4.3 Stress Relaxation Test

A metal frame that was custom-built in the HMB lab was used for the stress relaxation test. A feature of the metal frame is an adjustable platform. The height of the platform was determined by subtracting a half an inch from the height of the participant's iliac crest. This platform height ensured the subject's L5/S1 joint was aligned with the center of rotation of the platform. After platform adjustment, a custom-made harness was placed onto the participant. The tightness of the harness was adjusted to allow the subject to breath normally but unable to take a deep breath without difficulty. The tightness of the harness was determined from feedback provided by the subject [46] (Fig. 3.4).

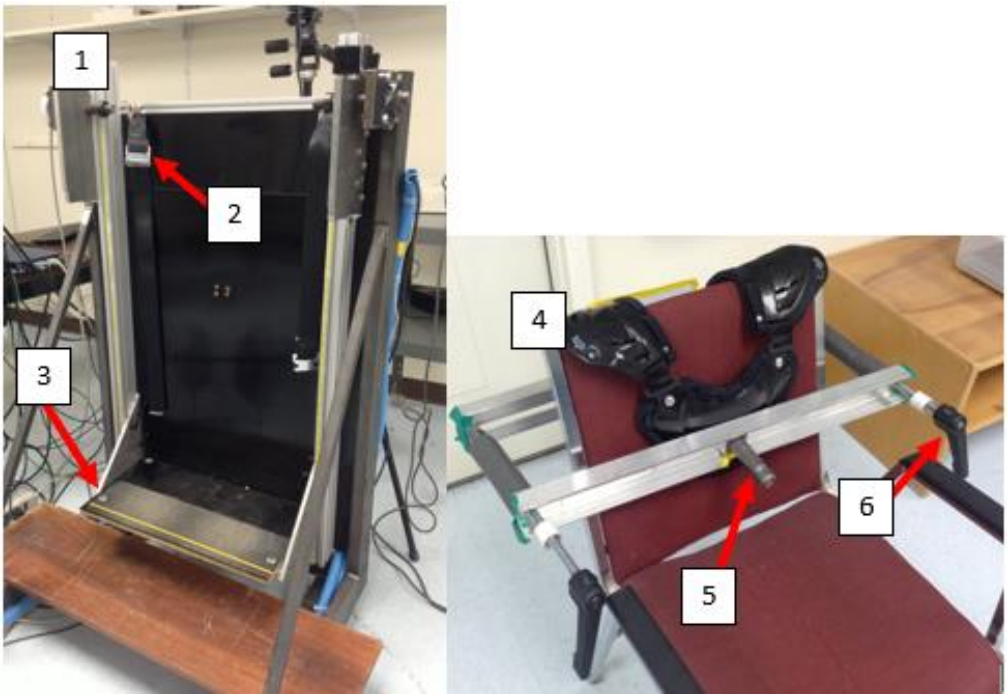


Figure 3.4: The Metal Platform and Harness

The metal platform and harness used in the stress relaxation tests. The metal platform (1) consists of an attached seat belt (2) and an adjustable leg platform (3). The harness (4) had an attachment point for the connecting rod (5) and adjustable handles for tightening (6).

After harness adjustment, the participant was instructed to stand on the platform. A seat belt was used to secure the subject to the platform and restrain movement of the lower body. A connecting rod kept the trunk upright throughout the stress relaxation test. One end of connecting rod was inserted onto the harness and the other end was attached to a fixed point on the test frame (Fig. 3.5).

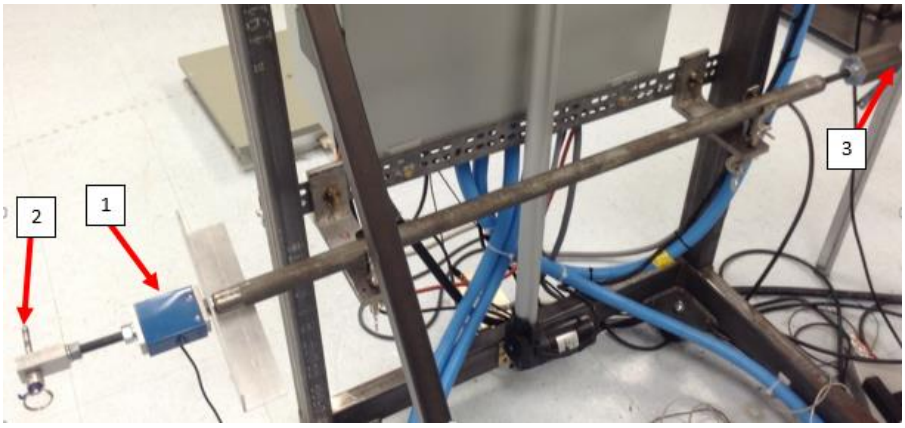


Figure 3.5: The Connecting Rod

The connecting rod has an attached load cell (1). One end of the connecting rod attaches to the test frame (2), and the other end attaches to the harness (3).

The length of the connecting rod was modified to obtain a neutral standing position for the subject. The fixed point on the test frame that one end of connecting rod attaches at was located on an adjustable platform, and a level was used to ensure the connecting rod was entirely horizontal (Fig. 3.6).

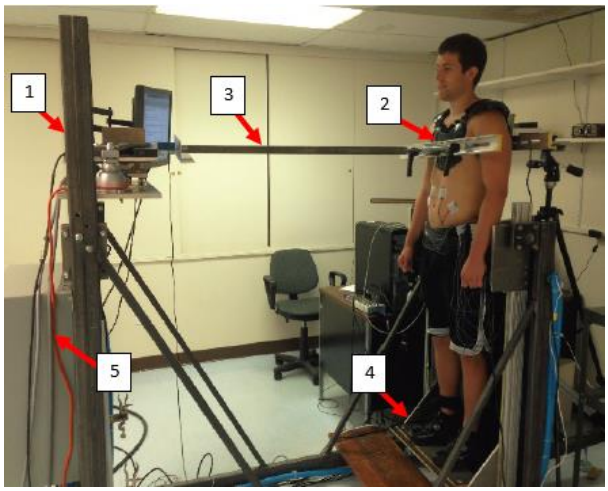


Figure 3.6: The Complete Device Set-Up for the Stress Relaxation Test

(Photo provided by [46]) The device consists of five components: 1.) the metal frame, 2.) the harness, 3.) the connecting rod, 4.) the leg platform, 5.) the electrical system.

For the stress-relaxation test, an actuator was used to raise the platform, resulting in the subject's lower limbs/pelvis rotating about their L5/S1 joint. The platform continued to rise until the lower back flexion achieved 70 percent of the subject's

maximum lumbar flexion angle (Fig. 3.7). The data collected from the accelerometers placed on the sternum and pelvis during the slow flexion/extension lower back range of motion tests was used to determine the subject's maximum lumbar flexion angle (see § 3.4.2). As the platform rose, the participant experienced passive stretching in their lower back. The natural tendency of the trunk to this passive stretching would be to lean back, but the connecting rod prevents the trunk from moving from its upright position. A load cell (Interface SM2000, Scottsdale, AZ) located on the connecting rod measured the passive stretching of the participant's lower back tissues throughout the test (Fig. 3.5). Trunk flexion was sustained for roughly four minutes before the platform was lowered. Participants were instructed to minimize any body motion throughout the four minutes (i.e. arms to the side, face forward, stay still, no talking etc…). The minimal movement instructions, as well as the fixed position of the trunk from the connecting rod and the pelvis from the seat belt minimized the active muscle response; thereby ensuring the recorded data collected from the load cell primarily reflected the passive resistance of the components in the passive musculoskeletal stabilizing subsystem. An accelerometer was placed on the side of the platform to measure the kinematics of the subject's lower limbs during the test [46][47].

Figure 3.7: Platform Rising During Stress Relaxation Test
(Photo provided by the HMB Lab at the University of Kentucky)

When the stress relaxation test finished, the participant was disconnected from the connecting rod and removed from the platform and harness.

3.4.4 Treatment

After completing the first data collection session, all participants underwent six sessions of SMT, specifically the HVLA technique (see § 2.4), over an approximately three week period. For the HVLA SMT, a pre-load force is applied onto a target joint. This study targeted the joints located in both the lumbar spinal region and the sacroiliac joint. Each participant received roughly two HVLA SMT sessions per week. Grant Sanders, a licensed chiropractor, and Arthur Nitz, PhD., a physical therapist, were the study personnel who performed the HVLA treatment.

After completion of the six sessions of HVLA SMT, participants completed a second data collection session. The second data collection session consisted of the exact same procedure used during the first data collection session.

3.5 Data Analysis

In-house MATLAB scripts (MathWorks, Natick, MA) were used to process the data collected for all tests.

3.5.1 Lower Back Range of Motion Tests

For the slow and fast flexion/extension range of motion tests, the accelerometers were used to collect kinematics data (Xsens, Culver City, CA) at a sampling rate of 50 Hz. An MT Manager program in combination with in-house built MATLAB scripts were used to process the data. The range of motion values were based off the angles that the thorax, pelvis and lumbar rotated during the bending movements. The thoracic rotation was determined from the accelerometer positioned at the T10 spinal level and the pelvic rotation from the accelerometer positioned at the S1 spinal level. Since each flexion/extension test consisted of three bending movements, the maximum thoracic and pelvic rotations were found at all three bending movements (Fig. 3.8). The lumbar rotation was calculated from the difference between the maximum thoracic and pelvic

rotation at each of the three bending movements. The three trunk angles were calculated in the sagittal plane for both slow and fast flexion/extension range of motion tests. Since the two range of motion tests involved three repetitive motions, for statistical analysis purposes, the averages of the three maximum thoracic, pelvis and lumbar rotation values were used [46].

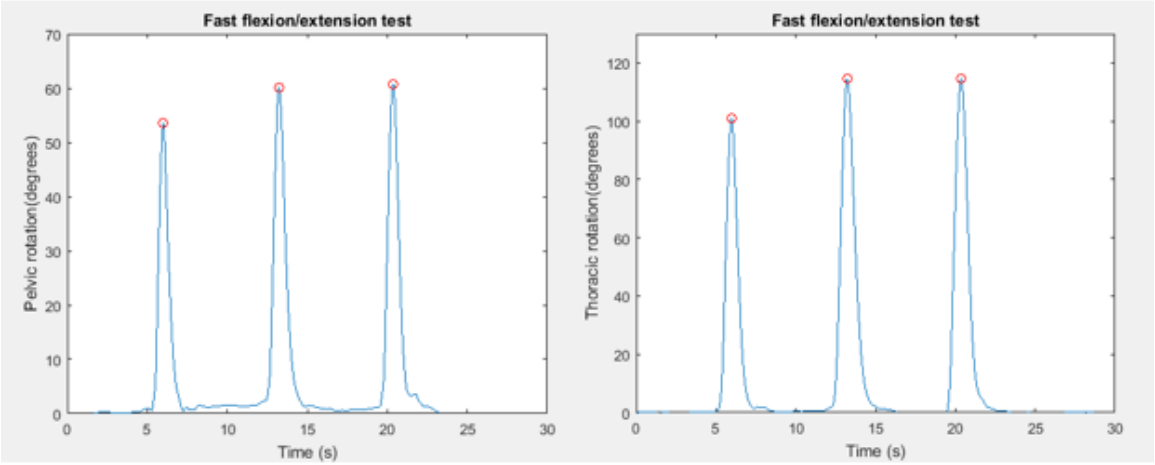


Figure 3.8: Rotation of the Pelvis and Thorax

An example of the MATLAB output showing the angles that the pelvis and thorax rotated during a fast flexion/extension test. The maximum rotation at each bending movement is circled in red.

3.5.2 Stress Relaxation Test

For the stress-relaxation test, the data from the load cell was sampled at a rate of 3000 Hz, and the accelerometer was sampled at a rate of 50 Hz. During the test, three measures were used to investigate the passive musculoskeletal stabilizing subsystem in the lower back: 1.) the bending stiffness in lower back tissues from the passive flexion as a result of the platform rising 2.) relaxation in the initial resistance of the lower back tissues during the four minute fixed flexion position and 3.) the energy dissipated [47].

For the first measure, the bending stiffness in the lower back was calculated for three lower back flexion angles (12.5%, 25%, and 100% of final flexion angle). The final flexion angle is the maximum flexion angle that the platform reaches during the test. This angle was calculated from the 70 percent of the maximum lower back flexion angle found during the slow flexion/extension range of motion test (see § 3.4.2). The bending

stiffness, K, was calculated at each of the flexion angles using equations 5-7 shown below [47]:

$$K_{@12.5\%\ of\ final\ flexion\ angle} = \frac{(M_e - M_s)}{(\theta_e - \theta_s)} \quad (5)$$

where M_e= moment at 12.5% of the final flexion angle, θ_e = lower back flexion angle at 12.5% of the final flexion angle, M_S = moment at the starting standing point, and θ_S = lower back flexion angle at the starting standing point

$$K_{@25\%\ of\ final\ flexion\ angle} = \frac{(M_e - M_s)}{(\theta_e - \theta_s)} \quad (6)$$

where M_e= moment at 25% of the final flexion angle, θ_e = lower back flexion angle at 25% of the final flexion angle, M_S = moment at the starting standing point, and θ_S = lower back flexion angle at the starting standing point

$$K_{@100\%\ of\ final\ flexion\ angle} = \frac{(M_e - M_s)}{(\theta_e - \theta_s)} \quad (7)$$

where M_e= moment at 100% of the final flexion angle, θ_e = lower back flexion angle at 100% of the final flexion angle, M_S = moment at the starting standing point, and θ_S = lower back flexion angle at the starting standing point

The moment at each of the three flexion angles was found by multiplying the load cell force measurement value at each specific flexion angle by the distance between the platform's axis of rotation and the harness. For the second measure, the relaxation in the initial resistance was calculated from the moment difference between the target point and the extension point (Fig. 3.9a). This relaxation in the initial resistance is also known as the relaxation moment. The target point is the point at which the platform reaches its final flexed position during the initial platform rising portion of the test. The extension point is the final point during the four minute fixed flexed posture position before the platform begins to lower. For the third measure, the energy dissipated during the test was found from the area within the closed lower back flexion moment curve (Fig. 3.9b) [47].

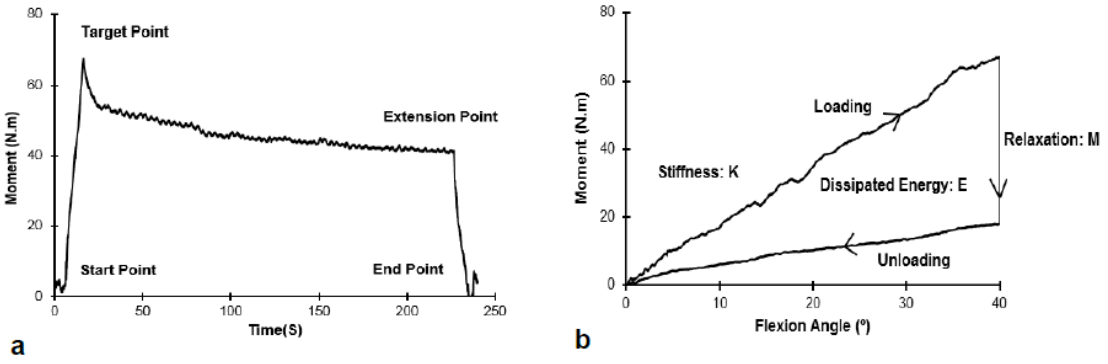


Figure 3.9a-b: Relaxation Moment and Energy Dissipated

(Photo provided by [47]) Figure 3.9a (left) is an example of the MATLAB output of the relaxation moment. Figure 3.9b (right) is an example of the MATLAB output of the energy dissipated throughout the stress relaxation test.

3.5.3 Seated Balance Tests Stability Measures

The force platform was sampled at a rate of 1000 Hz for all seated balanced tests. Three kinematic variability measures and one nonlinear stability analysis measure, described below, were used as stability measures for the seated balance tests.

3.5.3.1 Kinematic Variability

Kinematic variability is one type of measurement using the CoP displacements to evaluate the state of stability. The kinematic variability measurements include the path length traveled per second (PATH), root mean square (RMS) in the anterior-posterior (RMS_y), medial-lateral (RMS_x), and radial directions (RMS_r), and 95% ellipse area (EA). The equations for PATH, RMS and EA are shown below [44]:

$$PATH = \sum_{i=1}^{N-1} \frac{\sqrt{[CoP_x(i+1) - CoP_x(i)]^2 + [CoP_y(i+1) - CoP_y(i)]^2}}{Duration} \quad (8)$$

$$RMS = \sqrt{\frac{\sum_{J=1}^{N} CoP_j(i)^2}{N}} \quad (9)$$

where j=y (anterior-posterior), x (medial-lateral), r = $\sqrt{x^2 + y^2}$ (radial direction); N=total data points

$$EA = 2\pi 3\sqrt{(S_x)^2(S_y)^2 - (S_{xy})^2} \quad (10)$$

Where S_x and S_y are the standard deviation of the CoP in the x and y direction, and S_{xy} is the covariance (Eq. 11)

$$S_{xy} = \frac{1}{N} \sum_{i=1}^{N} CoP_x(i) CoP_y(i) \quad (11)$$

Following the same protocol established by Lee [44] at Virginia Polytechnic Institute and State University the kinematic variability was calculated using only the middle 40 seconds of the seated balancing tests. This was done to ensure an adequate duration of signal to reach process stationarity, as well as to avoid any transient artifact that may occur at the beginning and/or ending of the seated balancing tests. Process stationarity in a signal occurs when the statistical characteristics remain unchanged over time. Although kinematic variability is used as a stability measure, kinematic variability measures do not account for the neuromuscular-dynamic nature of the system. Therefore, nonlinear stability analysis also needs to be included when evaluating torso stability during seated balancing tests [44].

3.5.3.2 Nonlinear Stability Analysis

Maintaining a balanced position on an unstable seat is a dynamic movement (e.g. the unstable seat acts as a perturbation onto the system). This dynamic movement requires input from the neuromuscular system to regain an equilibrium (e.g. balanced) position following perturbations onto the system. This neuromuscular-dynamic behavior is accounted for in nonlinear stability analysis. The method of nonlinear stability analysis used in the present study is stabilogram diffusion analysis (SDA) [44].

SDA was first proposed by Collins and De Luca [48]. SDA uses a stabilogram constructed by averaging the squared CoP displacement between each of the CoP points and their corresponding time interval [48]. A MATLAB code was created to construct the stabilogram. The mean squared displacement of CoP was calculated from the equation below (Eq. 12) [44]:

$$< \Delta i^2 >_{\Delta t} = \frac{\sum_{j=1}^{N-m} (\Delta i_j)^2}{N-m} \quad (12)$$

For a Δt spanning over m data intervals, where i= y (anterior-posterior), x= (medial-lateral), r=radial, and N = total data points

Upon plotting, a short-term and a long-term region are identified. The short-term region utilizes an open-loop mechanism and the long-term region utilizes a closed-loop mechanism with regards to postural control. The transitional point (e.g. critical point) is the point at which the region transitions from short-term to long-term [48]. The critical point was considered to be the first maximum value that developed prior to 1 second [49]. The stability measure calculated from SDA used to evaluate torso stability is the scaling exponent (H). This exponent is calculated from the log log plot of the mean squared displacement of CoP points vs. the corresponding time interval. Similar to the previous plot, both a short-term scaling exponent (H_s) and a long-term scaling exponent (H_l) exist in the log log plot. The Hs and H_l values are found by taking ½ of the slope in the short-term region (H_s) and a ½ of the slope in the long-term region (H_l) [48]. Only the short-term scaling exponent, H_s, differentiates between healthy participants and LBP patients [40]. Therefore, only the short-term scaling exponent, H_s, was used in analysis. An H_s value greater than 0.5 suggest the behavior resulting from perturbations is not controlled and will progress toward infinity. An H_s value less than 0.5 suggests the behavior resulting from the perturbations will be controlled and drawn to the equilibrium state. Therefore, poor stability is characterized by a larger H_s value [44].

Besides SDA, there are two other methods of non-linear analysis available for evaluating torso stability: 1.) hurst rescaled range analysis and 2.) lyapunov exponent. The short-term scaling exponent, H_s, calculated in SDA is the best reliability measurement for comparing differences in inter-session torso stability [44]. Therefore, SDA was the only nonlinear analysis method used in the present study.

3.6 Statistical Analysis

A pre-post intervention study design was used to quantify changes in the active and passive musculoskeletal subsystems of the spinal stabilizing system and the resultant effects on the stability of the spine following six sessions of HVLA SMT. Statistical analyses were carried out using StatPlus Pro. (Version 5.9.8, AnalystSoft Inc., Walnut, CA, USA). The effects of HVLA SMT on the measures characterizing the passive musculoskeletal stabilizing subsystem (i.e., bending stiffness, relaxation moment, and energy dissipated) were investigated using one-way analysis of variance (ANOVA). In

addition to the effects of HVLA SMT, the effects of motion pace on the measures characterizing the active musculoskeletal stabilizing subsystem (i.e., angles of thoracic, pelvic, and lumbar rotation) were investigated using a two-way ANOVA. Finally, to evaluate the effects of HVLA SMT on the overall measures of spinal stability (i.e., kinematic variability and nonlinear stability analysis) a separate ANOVA was conducted for results associated with each of the three balancing support conditions. The p-value was accepted or rejected based on a 0.05 statistical significance level.

Chapter 4: Results

Summary of results are presented in Tables 4.1-4.3 with a more detailed description of results in the following sections. The data presented for each test are the average values of all six participants. The average values were used for both the first data collection session (pre-HVLA SMT) and the second data collection session (post-HVLA SMT).

4.1 Seated Balancing Tests

The averaged values for the three kinematic variability measures (RMS, PATH, EA) and the nonlinear stability analysis measure (SDA) measured during the seated balancing tests can be found in Table 4.1.

Table 4.1: Results from the Seated Balancing Tests

The measures characterizing the overall state of spinal stability. Specifically, the mean (SD) results of the kinematic variability and nonlinear stability analysis measured during the seated balancing tests for the three balancing support conditions.

	Variable	Units	100% Balancing Support Condition		75% Balancing Support Condition		50% Balancing Support Condition		100% Balancing Support Condition	75% Balancing Support Condition	50% Balancing Support Condition
			Pre-HVLA SMT	Post-HVLA SMT	Pre-HVLA SMT	Post-HVLA SMT	Pre-HVLA SMT	Post-HVLA SMT	Pre vs. Post HVLA SMT p-value	Pre vs. Post HVLA SMT p-value	Pre vs. Post HVLA SMT p-value
Kinematic Variability	RMS_X	mm	0.797 (0.357)	1.054 (0.434)	0.987 (0.312)	1.344 (0.791)	7.187 (10.776)	4.019 (4.217)	0.289	0.328	0.518
	RMS_Y	mm	1.394 (0.505)	1.254 (0.407)	1.416 (0.576)	1.554 (0.608)	7.384 (9.071)	3.952 (2.679)	0.611	0.696	0.395
	RMS_R	mm	0.813 (0.317)	0.769 (0.176)	0.910 (0.385)	1.119 (0.588)	6.652 (9.665)	3.219 (2.567)	0.772	0.481	0.420
	PATH	mm/s	8.863 (2.476)	7.686 (1.670)	9.457 (3.784)	9.722 (2.178)	85.542 (145.672)	32.171 (25.863)	0.357	0.885	0.398
	EA	mm^2	22.059 (14.696)	26.251 (19.779)	27.323 (20.536)	44.321 (44.842)	2622.441 (5889.217)	463.206 (821.059)	0.686	0.418	0.395
Nonlinear Stability	H_s (medial-lateral)	----	0.790 (0.005)	0.788 (0.006)	0.788 (.002)	0.789 (0.007)	0.795 (0.003)	0.793 (.007)	0.593	0.822	0.493
	H_s (anterior-posterior)	----	0.798 (0.004)	0.799 (0.003)	0.799 (0.003)	0.798 (0.004)	0.797 (0.004)	0.797 (0.004)	0.693	0.817	0.861
	H_s (radial)	----	0.767 (0.009)	0.777 (0.006)	0.761 (0.015)	0.761 (0.019)	0.735 (0.030)	0.739 (0.023)	0.074	0.995	0.805

4.1.1 Kinematic Variability

The averaged kinematic variability measures at each balancing support condition can be found in Table 4.1. For the first participant, the fourth trial of the 75% balancing support condition for the first data collection session was removed when calculating the kinematic variability results because upon review of the data, it was discovered that the equipment malfunctioned during that specific balancing test. No other data was removed when calculating the results of the kinematic variability measures for any other participant at any other balancing support condition. No significant differences were found in the kinematic variability stability measures between the first data collection session and the second data collection session (e.g. pre-SMT HVLA vs. post-SMT HVLA) at any of the three balancing support conditions.

4.1.2 Nonlinear Stability Analysis

The averaged nonlinear stability analysis measures at each balancing support condition can be found in Table 4.1. For the first participant, the fourth trial of the 75% balancing support condition for the first data collection session was removed when calculating the nonlinear stability analysis results because upon review of the data, it was discovered that the equipment malfunctioned during that specific balancing test. No other data was removed when calculating the results of the nonlinear stability analysis for any other participant at any other balancing support condition. No significant differences were found in the nonlinear stability measures between the first data collection session and the second data collection session (e.g. pre-SMT HVLA vs. post-SMT HVLA) at any of the three balancing support conditions.

4.2 Lower Back Range of Motion Tests

The averaged angles of thoracic, pelvic, and lumbar rotation measured during the lower back range of motion tests can be found in Table 4.2. No significant differences were found in the thoracic, pelvic, and lumbar rotation angles between the first data collection session and second data collection session (e.g. pre-SMT HVLA vs. post-SMT HVLA), and the pace of the test (e.g. slow vs. fast) did not significantly affect the angles of thoracic, pelvic, and lumbar rotation.

Table 4.2: Results from the Lower Back Range of Motion Tests

The measures characterizing the active musculoskeletal stabilizing subsystem. Specifically, the mean (SD) angles that the thorax, pelvic, and lumbar rotated during the slow and fast flexion/extension tests.

	Variable	Slow Flex./Ext.		Fast Flex./Ext.		Pre vs. Post HVLA SMT p-value	Pace p-value
		Pre-HVLA SMT	Post-HVLA SMT	Pre-HVLA SMT	Post-HVLA SMT		
Flexion/Extension	Thoracic Rotation	107.839° (17.765)	110.030° (11.768)	115. 949° (13.174)	115.054° (13.051)	0.912	0.268
	Pelvic Rotation	42.853° (11.952)	41.065° (14.592)	49.730° (10.081)	47.791° (14.053)	0.725	0.208
	Lumbar Rotation	64.986° (17. 585)	68.966° (14.062)	66.218° (13.987)	67.263° (15.433)	0.693	0.970

4.3 Stress Relaxation Test

For the stress relaxation test, three factors were investigated: 1.) bending stiffness, 2.) relaxation moment and 3.) energy dissipated. The averaged results of each factor are shown in Table 4.3.

Table 4.3: Results from the Stress Relaxation Test

The measures characterizing the passive musculoskeletal stabilizing subsystem. Specifically, the mean (SD) results of the bending stiffness, relaxation moment, and energy dissipated throughout the stress relaxation test.

Variable	Units	Pre-HVLA SMT	Post-HVLA SMT	Pre vs. Post HVLA SMT p-value
Bending Stiffness @ 12.5% of final lumbar flexion angle	Nm/rad	73.970 (57.397)	35.651 (15.556)	0.146
Bending Stiffness @ 25% of final lumbar flexion angle	Nm/rad	69.548 (41.802)	45.080 (52.446)	0.393
Bending Stiffness @ 100% of final lumbar flexion angle	Nm/rad	41.806 (23.614)	32.032 (28.447)	0.532
Relaxation Moment	Nm	15.810 (15.960)	10.071 (10.733)	0.482
Dissipated Energy	Nm*rad	10.540 (11.659)	4.787 (4.079)	0.280

4.3.1 Bending Stiffness

The averaged bending stiffness values in the lower back for the three lower back flexion angles (12.5%, 25%, and 100% of final flexion angle) can be found in Table 4.3. No significant differences were found in the bending stiffness values between the first data collection session and second data collection session (e.g. pre-SMT HVLA vs. post-SMT HVLA) at any of the three lower back flexion angles.

4.3.2 Relaxation Moment

The averaged relaxation moment values can be found in Table 4.3. No significant difference was found in the relaxation moment between the first data collection session and second data collection session (e.g. pre-SMT HVLA vs. post-SMT HVLA).

4.3.3 Dissipated Energy

The averaged dissipated energy values can be found in Table 4.3. No significant difference was found in the dissipated energy between the first data collection session and second data collection session (e.g. pre-SMT HVLA vs. post-SMT HVLA).

Chapter 5: Discussion

A connection between the reduction in movement, unusual stiffness of the spine, and spinal pain has been suggested to exist [50]. Therefore, this study investigated the changes in the bending stiffness, relaxation moment, dissipated energy, and lower back range of motion rotation angles to see if the measured values change following six sessions of HVLA SMT in healthy participants. This study also looked at changes in the state of stability of the spine using an unstable seat device, since instability of the spine has been identified as a risk factor for LBP development [4][5]. It was hypothesized that changes in lower back tissues of healthy individuals following six sessions of HVLA SMT would improve the state of spinal stability. The results of our study did not detect any significant changes in the state of spinal stability which could be due to either our small sample size or a lack of positive effect of HVLA SMT on healthy individuals.

5.1 Seated Balancing Tests

The purpose of the seated balancing tests was to empirically estimate the changes in the state of spinal stability after receiving six sessions of HVLA SMT. This change in the state of spinal stability was measured by the difference in the stability measures between the first and second data collection session. The two stability measures used were kinematic variability (RMS_X, RMS_Y, RMS_R, PATH, and EA) and nonlinear stability analysis (SDA). For this study, we hypothesized that the state of spinal stability would improve after the six sessions of HVLA SMT. This increase in the state of spinal stability after receiving the six sessions of HVLA SMT would be shown through a decrease in the stability measures between the two sessions [22][44]; however, our results did not find a significant difference in any of the stability measures between the two data collection sessions. Although not statistically significant, the 50% balancing support condition was the only balancing support condition were all of the kinematic variability measures decreased for the second data collection session. The participants therefore demonstrated a slightly better postural control, and therefore a greater state of stability, at the more demanding balancing support condition following the six sessions of HVLA SMT. Although this study did not deal with LBP patients, Radebold et al [40] found that the differences in the stability measures between LBP patients and healthy participants

became more evident as the balancing demands increased. Maybe the same is true for the HVLA SMT, at least with regards to the 50% balancing support condition for the kinematic variability. It is possible that the cumulative effects of the HVLA SMT only become evident at more demanding balancing conditions. The Hs showed no discernable pattern between the two data collection sessions, meaning all the balancing support conditions had Hs values that both increased and decreased (depending on the direction). As far as this author is aware, no other studies have evaluated the state of spinal stability following six sessions of HVLA SMT using the wobble chair, so unfortunately, there was no other data to compare our results with regards to the differences in the stability measures before and after six sessions of HVLA SMT.

Although not investigating HVLA SMT, Slota et. al [5] used the wobble chair to study acute changes in spinal stability following WBV. For that study, a significant acute increase was found for all of the stability measures following the participant's exposure to WBV. Our study investigated the cumulative effects of HVLA SMT. Therefore, our results suggest any potential acute changes in spinal stability following HVLA SMT have likely been recovered before the subsequent manipulation session.

Looking at the standard deviation of the kinematic variability measures, there was a wide range of values between the six participants, especially at the 50% balancing support condition. Just by visually observing each of the participants balancing performance during the sessions, it was evident that some of the participants found the task of maintaining a balanced position at the 50% balancing support condition extremely difficult, while others had no problems balancing at that level. Although the spring calibration process did account for each of the participants different anthropometry, it did not consider the different levels of postural control between the participants. Therefore, it might be beneficial to use a different spring calibration process, as shown in other unstable seated studies [5][45], to provide a more subject specific spring location based on the postural control of the participant.

The number of trials used at each balancing condition could have also affected the reliability of the stability measures between the two data collection sessions. Lee et al [44] determined the recommended trials necessary to achieve excellent reliability for

inter-session stability measurements. Unfortunately, those recommended numbers were between 8-20 trials (depending on the stability measure) for each balancing support condition. Obviously, performing 20 trials at each balancing support condition is not feasible due to both time constraints and fatigue concerns, which is why we used the 5 trials per balancing support condition protocol used by Lee [44]. If we eliminate the 100%, 75%, and 50% balancing support conditions protocol, and instead use only one spring location for the recorded seated balancing tests, [5][45] we could increase the number of trials at that specific spring location without worrying about time and fatigue constraints. This increase in the number of trials would likely increase the reliability of the inter-session stability measures.

5.2 Lower Back Range of Motion

For the lower back range of motion tests, accelerometers were used to investigate the changes in the angles of thoracic, lumbar, and sternum rotation following HVLA SMT. Although the active lower back range of motion does not directly characterize the active musculoskeletal stabilizing subsystem, the components of this subsystem are responsible for the spinal movement during the flexion/extension tasks. A reduction in the active spinal movement has been hypothesized to have a connection with spinal pain, [50] so it is possible that the HVLA SMT effect on pain reduction could also result in an increase in rotation angles during lower back range of motion.

The HMB lab at the University of Kentucky completed a study [47] investigating the affect that age has on the mechanical and neuromuscular behavior of the trunk. One of the subgroups of the entire study sample size (n=60) consisted of six healthy female participants between the ages of 22-28. Although the results have not yet been published, the aging study used the same protocol for the lower back range of motion tests as our study. Even though the aging study did not involve HVLA SMT, for comparison purposes, the aging study lower back range of motion measurements taken during the slow and fast flexion/extension tests for the 22-28 age range female subgroup were compared with the lower back range of motion measurements taken during the slow and fast flexion/extension tests during the first data collection session (e.g. pre-HVLA SMT) in our study. For the aging study, the mean (SD) thoracic, lumbar, and pelvic range of

motion values for the slow flexion/extension test were respectively 73.175 (17.056) ˚, 55.130 (12.146) ˚, and 18.0442 (6.364) ˚. The mean (SD) thoracic, lumbar, and pelvic range of motion values for the fast flexion/extension test were respectively 90.316 (13.376) ˚, 60.178 (8.781) ˚, and 30.138 (7.850) ˚. For our study, the range of motion values for both flexion/extension tests (Table 4.2) were slightly larger than the aging studies. A small sample size can result in an extreme measurement from a single participant significantly affecting the entire outcome measure. Therefore, the differences in the range of motion values between the studies could possibly be attributed to the small sample size of our study, and the small sample size of the 22-28 age range female subgroup in the aging study.

There is a limited amount of information available about the effect that HVLA SMT has on lower back range of motion [51]. To my knowledge, the only study that quantified the changes in the lower back range of motion after HVLA SMT on the lower back was completed by Stamos-Papastamos et al [52]. This study measured the acute changes in lumbar range of motion for asymptotic participants following one session of HVLA SMT, whereas our study investigated the cumulative changes in lower back range of motion after six sessions of HVLA SMT. The pre vs. post average (SD) lumbar range of motion values for the Stamos-Papastamos et al study were 54.22 (12.76)˚ and 56.07 (12.22) ˚. For that study, the HVLA SMT did not result in a significant difference in the lumbar range of motion value [52]. Our lumbar range of motion values (Table 4.2) were slightly higher than Stamos-Papastamos et al [52], but they appeared to follow the same behavior as Stamos-Papastamos et al of slightly increasing following the HVLA SMT. There is a possibility that changes in the lower back range of motion values following HVLA SMT may only occur in LBP patients, but the range of motion values for healthy participants did not appear to be affected by the six sessions of HVLA SMT.

5.3 Stress Relaxation

The HVLA thrust causes deformations onto the spinal column and adjacent soft tissues [12], so it is possible that those deformations could result in changes in the passive musculoskeletal stabilizing subsystem components. Our study examined the changes in the bending stress, relaxation moment, and dissipated energy following six sessions of

HVLA SMT. There is some evidence for the theory that a connection exists between an unusual stiffness of the spine and LBP [50]. Latimer et al [53] examined the differences in lumbar posteroanterior stiffness between LBP patients and healthy participants. Both groups completed an initial stiffness measurement. For the LBP patient group, a second stiffness measurement was taken at the point in time at which the LBP patients experienced an 80% reduction in the level of the LBP. The healthy participants completed a second stiffness measurement at a time frame similar to that of the LBP patients second stiffness measurement. The stiffness significantly decreased for the second stiffness measurement for the LBP patient group. The stiffness in the healthy participant group did not show a significant change for the second stiffness measurement. No treatment was actually provided in this study [53].

The HMB lab study [47], mentioned above (see § 5.2), investigating the affect that age has on the mechanical and neuromuscular behavior of the trunk also used the same protocol and equipment during the stress relaxation test as our study. Although the aging study did not involve HVLA SMT, for comparison purposes, the aging study measurements taken during the stress relaxation test for the 22-28 age range female subgroup were compared with the measurements taken during the stress relaxation test at the first data collection session (e.g. pre-HVLA SMT) in our study. For the aging study, the mean (SD) bending stiffness in the lower back at the 12.5%, 25%, and 100% of the final flexion angle were respectively 60.132 (61.456) Nm/rad, 44.253 (46.174) Nm/rad, and 31.425 (11.290) Nm/rad. The mean (SD) of the relaxation moment was 7.530 (4.145) Nm, and the mean (SD) of the energy dissipated was 2.247 (1.273) Nm*rad. For the aging study, the bending stiffness decreased as the flexion angle increased [47]. For our study, the bending stiffness values (Table 4.3) followed the same behavior as the aging study of decreasing as the flexion angle increased. Our relaxation moment and energy dissipated values were slightly larger than the aging study values, this could be attributed to the small sample size of our study and the small sample size of the 22-28 age range female subgroup in the aging study [47].

There is a limited amount of information about the bending stiffness changes to the spine following lumbar HVLA SMT. Stamos-Papastamos et al [52] has investigated

the bending stiffness of the lumbar spine following HVLA SMT. This study measured the acute changes in bending stiffness of asymptomatic participants following one session of HVLA SMT, whereas our study investigated the cumulative changes in the bending stiffness after six sessions of HVLA SMT. The Stamos-Papastamos et al. study also used a different method for measuring the bending stiffness. This study found that the one session of HVLA SMT had a negligible effect on the bending stiffness [52]. In addition to stiffness, we also investigated changes in the relaxation moment and dissipated energy following the application of a HVLA SMT on the lower back. No significant differences were shown in any of the measured values (bending stiffness, relaxation moment, and dissipated energy) for the stress relaxation test following the six sessions of HVLA SMT. Although the difference in the values between the two data collection sessions were not significantly different, all of the measured values decreased for the second data collection session. There is a possibility that significant changes in the stress relaxation measurements following HVLA SMT might only occur in LBP patients, but the measurements in healthy participants were not significantly affected by the six sessions of HVLA SMT.

5.4 Limitations

There were some limitations with our study that should be considered when examining our final results. Our study had a sample size that was small (n=6). The two data collection sessions were not performed at the same time of day. Obviously, the best study protocol would have been to conduct the data collection sessions at the same time of day to limit other variables from entering our data, but the sessions were scheduled based on the participant's availability. The six sessions of HVLA SMT were administered by two different clinicians. The clinician administering the HVLA SMT on the participant was chosen based on the availability of the participants and the two clinicians. Due to time constrains and concerns of fatigue, only 5 trials were performed at each of the three balancing support conditions, so the inter-session reliability may be low based on Lee et al. [44] suggestions about the number of trials necessary to achieve excellent inter-session reliability.

In summary, HVLA SMT is a commonly used treatment option utilized by patients suffering from LBP. A connection has been suggested to exist between reduction in movement, unusual stiffness of the spine, and spinal pain [50], so this study used lumbar range of motion tests and a stress relaxation test to investigate two of the above mentioned factors (i.e. stiffness of spine and movement). These two factors are controlled by the components of the active and passive musculoskeletal stabilizing subsystems of the spine. An unstable seat device (wobble chair) was used to investigate the changes in the state of spinal stability, since instability of the spine may lead to the development of LBP [4][5]. Therefore, investigating the above factors can provide us more information about the underlying mechanism(s) behind HVLA SMT. No significant differences were found in any of the test measurement values after the six sessions of HVLA SMT. Future studies that address the limitations found within our study, as well as other limitations not addressed, may observe a different conclusion.

Chapter 6: Future Work

6.1 Future Work

Obtaining a better understanding about the acting mechanism behind HVLA SMT and other manual therapies used for the treatment of non-specific LBP is essential for the improvement of LBP treatment and management. Therefore, other subsequent studies are necessary to achieve a better understanding about the acting mechanism behind HVLA SMT and other manual therapies, as well as the affect that these treatments may have at different treatment locations and for different sample populations.

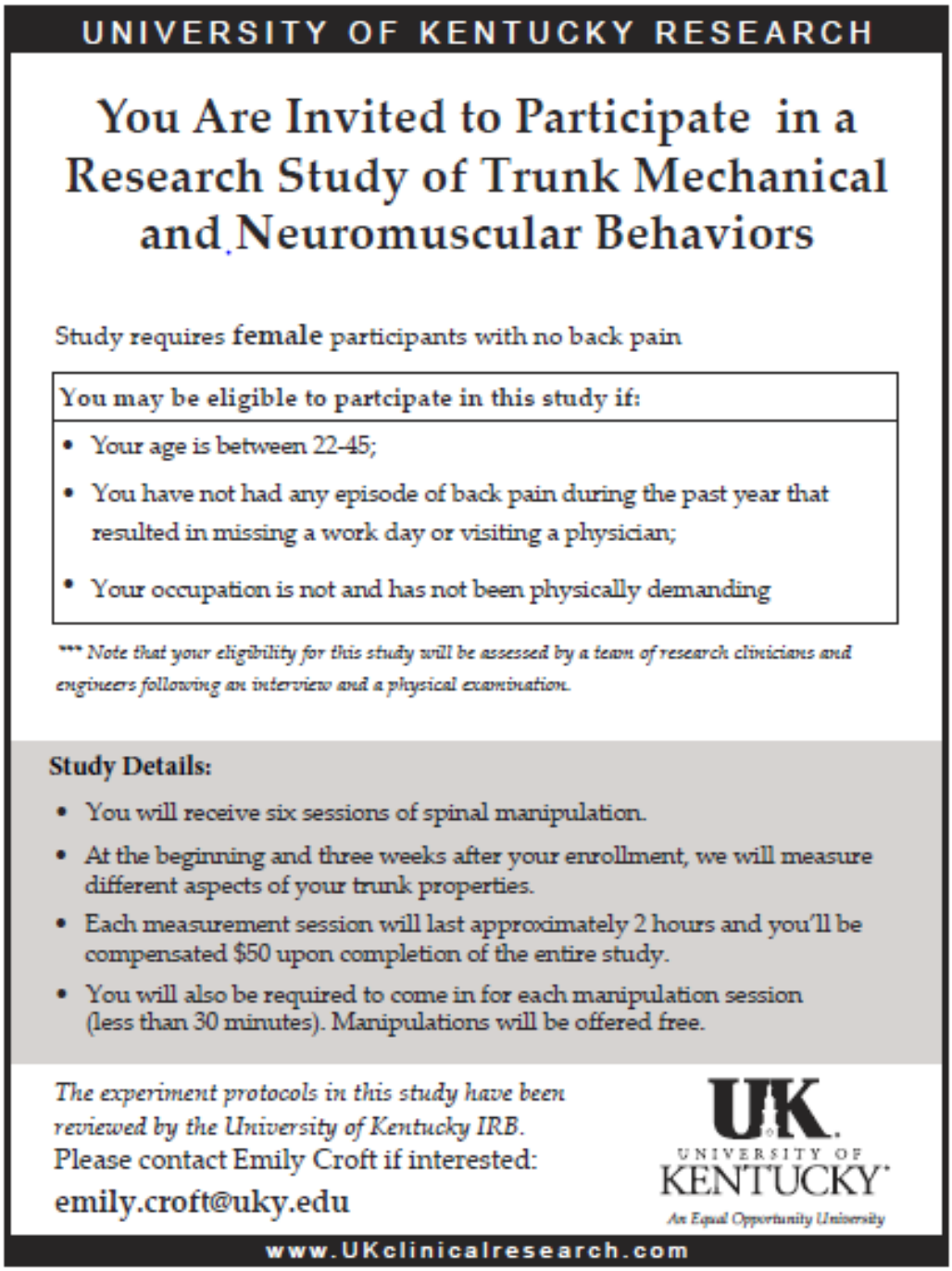
Our results may have been affected by certain constraints within our study, so all future studies should consider such limitations. Future studies should consider using a larger sample size of participants. Future studies may also want to use a spring calibration process that is determined by the participants existing postural control level instead of the participants anthropometry [5][45]. As long as a single spring location is sufficiently challenging, participants may only need to complete the recorded seated balancing tests at a single spring location. Using only one spring location would allow the participant to complete a greater number of seated balancing tests at a given spring location, and therefore, obtain a better inter-session reliability for the stability measures [44].

This study specifically investigated the HVLA SMT changes within healthy participants, so future studies should examine the HVLA SMT changes within a LBP patient population. Although our study yielded no statistical difference in any of the test measures between the two data collection sessions, our original hypothesized changes may only occur in participants actually suffering from LBP. Studies that use a LBP population should also clearly define the conditions of the LBP patient group (e.g. whether the patient is suffering acute, subacute, or chronic LBP and the severity of the LBP), since patients suffering from LBP at different severity levels and time frames may react differently to the HVLA SMT. Our study applied the HVLA treatment on the lumbar and sacroiliac joints, but HVLA SMT can also be performed at other locations of the spine. Although not related to LBP, HVLA SMT has also been suggested as a possible treatment option for neck pain when the HVLA SMT is applied to the thoracic region of the spine [9][54]. Therefore, future studies could investigate other spinal

treatment locations because these location may have a more favorable response to the HVLA SMT than the lumbar and sacroiliac joints.

Appendix A: Institutional Review Board Forms

A.1 Study Advertisement Flyer



A.2 Consent Form

IRB Approval
14-0460
THIS FORM VALID
11/11/14 — 7/13/15

Consent to Participate in a Research Study

Acting Mechanisms of Spinal Manipulation for Low Back Pain - Mechanical Pathways

WHY ARE YOU BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are being invited to take part in this study because you are a female aged 22-45 with subacute low back pain (i.e. the low back pain (LBP) has lasted for > 4 weeks but < 12 weeks, and the reason behind the LBP is unclear), or a female aged 22-45 without significant low back pain in the past year. This is a pilot research study examining the reasons why physical therapy (i.e. spinal manipulation) alleviates subacute non-specific low back pain (LBP). If you volunteer to take part in this study, you will be one of about 24 people to do so.

WHO IS DOING THE STUDY?

The person in charge of this study is Emily Croft, B.S., of University of Kentucky's Department of Biomedical Engineering. The principal investigator (PI) is a graduate student and she is being guided in this research by her advisor, Babak Bazrgari, PhD. Arthur Nitz, PhD, a certified physical therapist and professor at the University of Kentucky, along with other members of the research team will also be assisting at different times during the study.

WHAT IS THE PURPOSE OF THIS STUDY?

Although we know spinal manipulation is used to relieve LBP, the reason why spinal manipulation works is still unclear. This study will help increase our understanding on how spinal manipulation relieves LBP, by investigating the changes in the mechanical and neuromuscular behaviors of the human trunk post spinal manipulation, in people with subacute non-specific LBP. By doing this, we hope to learn the reasons why spinal manipulation relieves LBP. This study is a part of our ultimate goal for understanding the causes of non-specific LBP and improving its control and management.

ARE THERE REASONS WHY YOU SHOULD NOT TAKE PART IN THIS STUDY?

This study requires repetitive mild physical exercise such as freely bending forward and back, bending laterally, and twisting. It also requires you to stand for at least 2 hours with regular short breaks (to rest) in between. Your eligibility to participate in this study will be determined by the participating research team. All low back pain (LBP) participants must have already seen Dr. Scott Black and been given self-care as the treatment recommendation for the LBP. All participants, both healthy and those with LBP (i.e. those LBP patients who have been deemed eligible for this study by Dr. Black), will come in for an initial screening before any data collection sessions or spinal manipulations occur. This initial screening will involve you filling out a health history questionnaire about your medical history that is relevant to this study. A licensed chiropractor or a certified physical therapist who is qualified in performing spinal manipulations will then perform a physical examination. This physical examination will be used to determine whether your LBP qualifies as a subacute non-specific LBP and verify spinal manipulation is not harmful to you, as well as assure lack of any spinal deformity or clinical instability. Based on some additional criteria, they will also assess if you are fit enough to participate in this study. If you do not meet these additional criteria, you'll be excluded from the study and will be given the reason why you should not take part in this study. For example, if your back pain prevents you from bending forward or backward, or standing for

~ 20 minutes without a break, you will be excluded from the study. Participants with an open or pending case related to LBP will also be excluded from the study.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The data collection will be conducted at the Human Musculoskeletal Biomechanics Lab (room #513 in the Robotics and Manufacturing Building) in the Department of Biomedical Engineering. The actual data collection will take place only during your first and last visits before you receive spinal manipulation at the beginning of the three weeks, and after you receive your final HVLA spinal manipulation. Each of those data collection visits will take about 2 hours. The total amount of time you will be asked to volunteer for data collection is <6 hours over a 21 day period. You will also be required to come in twice per week for three weeks to receive spinal manipulation (i.e. you will receive a total of 6 spinal manipulations). The spinal manipulations will take place in either the Charles T. Wethington Building (College of Health Sciences) in rooms 224 and 222 (the room numbers will determined by availability), or the Human Musculoskeletal Biomechanics Lab (room #513 in the Robotics and Manufacturing Building) in the Department of Biomedical Engineering. Each spinal manipulation will take less than 30 minutes. Prior to any data collection sessions or spinal manipulations, all eligible participants who returned the signed consent form will need to undergo an initial screening by the study clinician to verify eligibility. This initial screening will take place in either the Charles T. Wethington Building (in rooms 224 or 222 depending on availability), or in the Human Musculoskeletal Biomechanics Lab (room #513 in the Robotics and Manufacturing Building) in the Department of Biomedical Engineering and will take approximately 40-60 minutes.

WHAT WILL YOU BE ASKED TO DO?

During each spinal manipulation session, you will receive spinal manipulation by a licensed chiropractor or a certified physical therapist who is qualified in performing spinal manipulations. During the data collection sessions, we will record measures of trunk mechanical behaviors (TMB). The first data collection will occur at the beginning of the study before you receive the spinal manipulation, and the second data collection will occur at the end of the 3 week enrollment after you receive your final spinal manipulation. To measure TMB, we will attach adhesive markers and sensors on the skin around your abdomen and back. These sensors include EMG electrodes to measure the activity of your muscles and position sensors to measure your body posture and movements. After some preliminary warm up stretches, we will ask you to bend forward and back, sideways, and twist at a comfortable speed. In another test, we will ask you to stay relaxed while we raise your legs and measure your body resistance against such movement. In another test, you will be asked to balance on an unstable seat, and we will measure your ability to hold a balanced seated posture on an unstable seat.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

To the best of our knowledge, the things you will be doing have no more risk of harm than you would experience in everyday life. The risks of this study are minor. However, they include a potential for skin irritation due to the adhesives used in the tape and electrode markers. You may also feel some temporary muscle soreness such as might occur after mild exercising. Subjects participating in physical conditioning may experience muscle soreness and/or musculoskeletal injury associated with inherent risks of cardiovascular, strength training and therapeutic exercise. To minimize these risks you will be asked to warm-up before the tasks and tell us if you are aware of any history of skin-reaction to tape, history of musculoskeletal injury, or cardiovascular limitations. During prolonged testing, you may feel dizzy or light-headed, and there is a small risk that you could faint. To minimize these risks, you will be asked several times if you are experiencing such symptoms; if so, you will be asked to walk around or sit down as appropriate. In addition, hunger may exacerbate such risks, so you will be asked not to come to experimental sessions hungry, and small snacks will be made available should you become hungry.

Risk associated with the treatment: HVLA have been reported to be generally safe. Nevertheless, the reported harms associated with HVLA can be divided into: 1) relatively common, minor, temporary, and self-limiting harms (e.g., side effects), or 2) very rare, more serious adverse events (e.g., lumbar disc injury, cauda equine syndrome, spinal cord ischemia or infract, vertebral fracture, and epidural hematoma). Reports of serious complications resulting from lumbo-pelvic joint manipulation seem to be limited. The most serious risk for lumbar manipulation is cauda equina syndrome. A review of literature over a 77-year period found 10 reports of cauda equina

syndrome. Performing manipulations under anesthesia is thought to increase the risk of cauda equina syndrome. Avoidance of these situations is thought to reduce the risk of cauda equine. The frequency of these adverse effects is difficult to estimate, however one review reported that the rate of disc herniation or cauda equina syndrome after lumbar SM was 1 per 3.7 million procedures; the confidence interval around this estimate is unknown but likely to be wide. In another study, it was estimated that the rate of occurrence for cauda equina syndrome resulting from lumbar manipulation is less than one occurrence per 100 million lumbar manipulations.

In addition to the risks listed above, you may experience a previously unknown risk or side effect.

WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?

By participating in this study, you will also help to increase our understanding on the ways spinal manipulation alleviates LBP. The only personal benefit can be 6 free sessions of spinal manipulation by a chiropractor or a certified physical therapist. We hope to make this research experience interesting and enjoyable for you where you may learn experimental procedures in biomechanical sciences.

Although there is evidence to support spinal manipulation as a treatment option for alleviating low back pain, we cannot guarantee you will benefit from the spinal manipulation.

DO YOU HAVE TO TAKE PART IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering.

IF YOU DON'T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?

If you do not want to be in the study, there are no other choices except not to take part in the study.

WHAT WILL IT COST YOU TO PARTICIPATE?

We will do our best to minimize any cost to you. Potential cost may include traveling and parking cost.

WHO WILL SEE THE INFORMATION THAT YOU GIVE?

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. Signed consent forms and phone screening data sheets will be kept in a designated cabinet in the Human Musculoskeletal Biomechanics Lab. Please note that only authorized people have access to this lab and only investigators of this application will be provided access keys to this cabinet. Collected data during experiments will be saved on lab computers and will be backed up on two portable hard drives (one will be kept in the PI's office and another in a distant location).

All study personnel will have access to de-identified collected data, and data with any identifying information will be stored for six years after the end of study and will be deleted from hard drives and computers afterward.

IRB

We will keep private all research records that identify you to the extent allowed by law. However, there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court. Also, we may be required to show information which identifies you to people who need to be sure we have done the research correctly; these would be people from the University of Kentucky.

CAN YOUR TAKING PART IN THE STUDY END EARLY?

If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. You will not be treated differently if you decide to stop taking part in the study.

The individuals conducting the study may need to withdraw you from the study. This may occur if you are not able to follow the directions they give you, or if they find that your being in the study is more risk than benefit to you.

ARE YOU PARTICIPATING OR CAN YOU PARTICIPATE IN ANOTHER RESEARCH STUDY AT THE SAME TIME AS PARTICIPATING IN THIS ONE?

You may take part in this study if you are currently involved in another research study. It is important to let the investigator know if you are in another research study. You should also discuss with the investigator before you agree to participate in another research study while you are enrolled in this study.

WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?

It is important for you to understand that the University of Kentucky does not have funds set aside to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Kentucky will not pay for any wages you may lose if you are harmed by this study.

You do not give up your legal rights by signing this form.

The natural history of low back pain (LBP) (i.e. whether you recover from the LBP or the LBP develops into chronic LBP) is positive (most individuals recover from LBP within 12 weeks). However, the actual cause of most low back pain cases is unknown because of the complexity of the back. As a result of this complexity, approximately 5-10% of individuals who experience subacute LBP will eventually develop chronic LBP. If your back pain persists or even worsens during the course of this study, we strongly recommend you to see your doctor.

WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

You will receive $50 for the data collection sessions, but will only receive this compensation upon completion of the entire study. Participants who drop out of the study before completion will receive no monetary compensation. The money will be paid within two weeks following the second data collection session by check. The data collection sessions will require a total of around 4-6 hours for the complete study.

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the principal investigator, Emily Croft, B.S. at 217-216-0347. If you have any questions about your rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky at 859-257-9428 or toll free at 1-866-400-9428. We will give you a signed copy of this consent form to take with you.

IRB

WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT YOUR DECISION TO PARTICIPATE?

If the researcher learns of new information in regards to this study, and it might change your willingness to stay in this study, the information will be provided to you. You may be asked to sign a new informed consent form if the information is provided to you after you have joined the study.

_____ _____

Signature of person agreeing to take part in the study Date

_____

Printed name of person agreeing to take part in the study

_____ _____

Name of [authorized] person obtaining informed consent Date

_____

Signature of Investigator

A.3 Participant Information and Screening Form

PARTICIPANT INFORMATION AND SCREENING FORM

(Form-M)

Project Title:

Acting Mechanisms of Spinal Manipulation for Low Back Pain - Mechanical Pathways

Investigators:

Emily Croft, Department of biomedical engineering, UK
Babak Bazrgari, Department of biomedical engineering, UK
Arthur J. Nitz, College of Health Sciences, UK

Contact information:

Emily Croft
513 Robotics and Manufacturing Building
Phone: 859-323-3876
Email: emily.croft@uky.edu

Participant #: _____ (filled out by the experimenter) **Date:** _____

Part I – Verification of Advertised Criteria

Age group: 22-45

Gender: Female

Physical exposure at work: minimal moderate high

**Occupations that involve minimal exposure to forceful and repetitive exertion as well as awkward postures. Examples of occupation with minimal exposure include: clerical work, teaching, studying, house work, medical practice and all other occupations with a university educations. Moderate level exposure may include occupations like factory work, plumbing, carpentry, and farming. High level exposure occupations may include dock work, construction work, and sport.

During the past 12 months, have you had any episode of back pain that resulted in visiting a doctor or missing a work-day? Yes No

If the answer to previous question is Yes, has your consulting physician told you to remain active and instructed you for self-care for your back pain problem? Yes No

*** **Invite for a visit only if participant give the underlined answered for all the above questions**

Part II – Personal Information

Name: (last) _____, (first) _____

Phone: _____ Email: _____

Address: _____

_____

Age: _____

Gender (please circle): Male - Female

Race:

Caucasian African American Asian American Indian/Alaska Native

Native Hawaiian/Pacific Islander Other:_____

Occupation: _____ (Current) _____ (Previous)

Length of time at present occupation: _____ years

Part III- Psychosocial risk assessment

Has participant had a history of back pain?

Conduct this part of the questionnaire for all participants. (Healthy participants should answer N/A to those questions that are not relevant to them.)

1- How long did your last back pain episode last?

1) 0 days 2) 1-2 days 3) 3-7 days 4) 8-14 days 5) 15-30 days
6) 1 month 7) 2 months 8) 3-6 month 9) 6-12 months 10) over 1 year

2- For the 18 months period prior to your last back pain episode, how many days of work did you missed?

1) 0 days 2) 1-2 days 3) 3-7 days 4) 8-14 days 5) 15-30 days
6) 1 month 7) 2 months 8) 3-6 month 9) 6-12 months 10) over 1 year

3- Is your work heavy or monotonous? Rate by a number between 1 (not at all) and 10 (extremely).

4- How would you rate the pain of your last back pain episode? Rate by a number between 1 (no pain) and 10 (as bad as it could be).

5- During the 3 months prior to your last back pain episode how often you experienced pain episodes? Rate by a number between 1 (never) and 10 (always).

6- Following Q#5, on average, how bad was your pain if you experienced pain during the last 3 months prior to your last back pain episode? Rate by a number between 1 (no pain) and 10 (as bad as it could be).

7- Based on all the things you do to cope, or deal with your pain, on an average day, how much are you able to decrease it? Rate by a number between 1 (can't decrease) and 10 (can decrease it completely).

8- How tense or anxious have you felt in the past week? Rate by a number between 1 (absolutely calm and relaxed) and 10 (as tense as I've ever felt).

9- How much have you been bothered by feeling depressed in the past week? Rate by a number between 1 (not at all) and 10 (extremely).

10- In your view, how large was the risk that your last pain might become persistent? Rate by a number between 1 (no risk) and 10 (very large risk).

11- In your estimation, what were the chances that you would be working in 6 months? Rate by a number between 1 (no chance) and 10 (very large chance).

12- If you take into consideration your work routines, management, salary, promotion possibilities and work mates, how satisfied are you with your job? Rate by a number between 1 (not at all satisfied) and 10 (completely satisfied).

Part III - Continue

Here are some of the things which other people have told us about their back pain. For each statement rate by a number between 1 (completely disagree) and 10 (completely agree) to say how much physical activities, such as bending, lifting, walking or driving would affect your back.

13- Physical activities make my pain worse.

14- An increase in pain is an indication that I should stop what I am doing until the pain decreases.

15- I should not do my normal work with my present pain.

Here is a list of five activities. Please rate by one number that best describes your ability to participate in each of these activities during your last episode of back pain. Rate by a number between 1 (couldn't because of the pain) and 10 (could do without the pain being a problem)

16- I could do light work for an hour.

17- I could walk for an hour.

18- I could do ordinary household chores.

19- I could go shopping.

20- I could sleep at night.

A.4 Physical Examination Form

PHYSICAL EXAM

Subject #_____ Date:_____

Blood Pressure_____mmHg	Height ____ft ____in	Weight _____lbs

Level of Pain (0 to 10) _____	Duration of Pain _____ Weeks

RANGE OF MOTION

Cervical

Motion	Active	Passive	Pain
Flex			
Ext			
RLF			
LLF			
R Rot			
L Rot			

Thoracic

Motion	Active	Passive	Pain
Flex			
Ext			
RLF			
LLF			
R Rot			
L Rot			

Lumbar

Motion	Active	Passive	Pain
Flex			
Ext			
RLF			
LLF			
R Rot			
L Rot			

Notes:_____

_____

_____

_____

SENSORY EVALUATION (WARTENBERG WHEEL)

	Left	Right
UE		
LE		

REFLEXES	Left	Right
Biceps		
Brachioradialis		
Triceps		
Patellar		

Achilles		
Hoffmann's		
Plantar/Babinski		

MOTOR EVALUATION	Left	Right
Deltoids C5 C6 Axillary N.		
Wrist Extension C6 C7 C8 radial N.		
Wrist Flexion C6 C7 C8 Median N. Ulnar N.		
Finger Flexion C7 C8 Median N. Ulnar N.		
Finger Abduction C8 T1 Ulnar N.		
Finger Adduction C8 T1 Ulnar N.		
Hip Flexion L1 L2 L3 Femoral N./L1-L3 nerve roots		
Hip Adduction L2 L3 L4 Obturator N.		
Hip Abduction L4 L5 S1 Superior Gluteal N.		
Ankle Dorsiflexion w/ Inversion L4 Tibial N.		
Extensor Hallicus Longus L4 L5 S1 Deep Peroneal N.		
Ankle Plantarflexion w/ Eversion S1 Sup. Peron N.		

ORTHOPEDIC TESTS FOR LUMBAR/SI/HIP REGION

Test	Left	Right
Kemp's		
Bechterew's		
Patrick's/Fabere		
Yeoman's		

SPINAL EVALUATION (Motion Palpation)

Left	Level	Right
	L1-L2	
	L2-L3	
	L3-L4	
	L4-L5	
	L5-S1	
	SI	

Additional Notes:_____

_____

_____

_____

_____

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