Original Research

The Active Straight Leg Raise Test and Lumbar Spine Stability

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Objective: To determine the utility of the active straight leg raise (ASLR) test as a screen of lumbar spine stability and abdominal bracing (AB) ability.
Design: A biomechanical study of the ASLR test as a clinical evaluation of lumbar spine stability and AB.
Setting: Clinical research laboratory.
Participants: Fourteen participants who were currently asymptomatic for back pain and leg pain were evaluated.
Methods: Spine posture, muscle activation, and pressure distributions underneath the supine subject were determined.
Main Outcome Measurements: An estimation of lumbar spine stiffness, a direct correlate with spine stability, was obtained using an anatomically detailed spine model.
Results: AB during the ASLR reduced the center of pressure (CoP) movement on a strain-based pressure mat in lumbar rotation ($P < .0125$) as well as reducing directly measured lumbar rotation ($P = .02$). Active AB increased lumbar spine stiffness ($P < .002$). Regression analysis between stiffness and CoP movement suggested that different participants used different strategies to control torso motion.
Conclusions: This study demonstrates that the ASLR has utility as a screen of lumbar spine stability and AB ability. The ASLR maneuver can assess control of lumbar rotational movements in the transverse plane. Finally, this study demonstrated that AB can measurably improve the rotational (transverse plane) stiffness of the lumbar spine.

INTRODUCTION

The active straight leg raise test (ASLR) is suggested as a clinical indicator of lumbopelvic stability [1-3]. Poor performance during the ASLR is associated with postpartum sacroiliac (SI) pain [3]. Furthermore, O'Sullivan et al [4] suggested that altered kinematics of the diaphragm and pelvic floor are likely present in those with a positive test. A positive test has been reported to reproduce the patient's characteristic pain or demonstrate weakness on manual muscle testing or manual resistance [2,3]. The test may be performed actively with or without manual resistance or abdominal bracing (AB). AB has been suggested as a maneuver to enhance the stability of the SI joint and thus reduce pain when the ASLR test is positive [2,3], although the mechanism for this has not been demonstrated. Clinical observation also suggests that lumbar axial rotation may occur during the ASLR, and the inability to limit this motion may indicate inadequate lumbar control. Light AB has been demonstrated to stiffen the lumbar spine [5,6], and may serve to improve the active control of lumbar spine motion. Thus, the purpose of this study was to investigate the applicability of the ASLR test for evaluating lumbar spine stability in a rotational mode, and to determine whether AB can stiffen and improve lumbar control during this test.

It appears that pelvic girdle stability is influenced by muscular activation of surrounding muscles [7,8]. Sapsford and Hodges [9] demonstrated that conscious contraction of the abdominal wall led to concomitant activation of the pelvic floor muscles. Furthermore, patterns of abdominal contraction creating hoop stresses [10] and pelvic ring compression [7,8] suggest a crucial role for the muscular control system in enhancing lumbopelvic stability. Increased muscle activation results in more stiffness, and this is directly linked to a system that is more stable and will deform less under a given load or perturbation [11].

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Similar abdominal activation techniques that may assist in pelvic stability also affect lumbar stability. AB, which activates the 3 layers of the abdominal wall (external oblique, internal oblique, transverse abdominis) and rectus abdominis, with no drawing in of the navel, has been quantified to enhance lumbar spine stability [5,6]. Relatively low levels of abdominal wall co-contraction are needed to ensure sufficient stability during performance of many activities of daily living [12]; much higher levels of activation may become necessary as the demands of the task increase. Thus, the activation state of the musculature is matched to the demands of the task to ensure "sufficient stability."

Although sufficient stability ensures that the spine will not buckle, it also ensures that the spine will not give way under imposed torque, including about the axial rotation axis (transverse plane). Lumbar spine axial rotation has been suggested to be the most difficult movement to control [13]. Not surprisingly, an inability to control rotation has been linked to occupationally related low-back disorders [14]. It would be helpful clinically to assess the ability to control axial rotation of the pelvis and lumbar spine. In this way the ASLR test may have potential to serve as a clinically useful functional screening test. Individuals classified as being candidates for stabilization training have been demonstrated to have aberrant lumbopelvic motion patterns [15,16].

The hypothesis tested in this study is that the ASLR test is linked to lumbar spine rotational stiffness, which is a surrogate measure of lumbar spine stability [17]. Specifically, to assess this, axial rotation and stiffness about the axial rotation axis of the lumbar spine was quantified. It was further hypothesized that AB would serve to increase spine stiffness and decrease axial rotation of the lumbar spine during performance of the ASLR. The majority of clinicians do not have the instrumentation to measure quantities that are used for calculating spine stability. For this reason several instrumentation approaches were used. Pressure distribution between the supine patient and the table was used given that this was believed to be a surrogate clinical indicator of stability years ago by Jull and colleagues [18]. Although they assessed pressure with a bladder sensitive to sagittal spine motion, it was not sensitive to lateral shifts. Nor could the approach indicate centers of pressure. For this reason a pressure-sensitive mat between the participant and the table was used in this study. In addition 3-dimensional spine motion was quantified together with torso muscle activation profiles captured with surface electromyogram (EMG). These approaches added insight into whether the ASLR may act as a surrogate indicator of a form of stability, or at least postural control, that is easily administered during patient examination in the clinical setting.

MATERIALS AND METHODS

Participants

A sample of 14 participants (5 men and 9 women), average age of 26.9 years (SD, 13.8 years), average height of 168.8 cm (SD, 6.5 cm), and average weight of 68.4 kg (SD, 8.4), were assessed during performance of the ASLR tests. The exclusion criteria were that all had to be currently asymptomatic for back pain and leg pain, and symptom-free for the previous year. The subjects were of varying levels of fitness. Before beginning testing, all participants read and signed an informed consent document that had been approved by the Office of Research Ethics at the University of Waterloo.

Lumbar spine stiffness was quantified using an anatomically detailed EMG-driven model of the lumbar spine in a subsample of 7 participants [19,20]. Given the reliance of this approach on estimates of muscle activation, these 7 participants were chosen from the pool of 14 for having the most suitable EMG.

Procedures

For the ASLR test participants lay supine on a table and were asked to actively raise their right leg from the table while keeping their knee straight (Figure 1). The right leg was raised with hip flexion until the heel was 20 cm above the table and held for approximately 5 seconds. The ASLR was assessed in 2 separate randomly ordered trials, one with and one without AB. A brief rest of at least 10 seconds was allowed between each test variation.

Active AB was cued in the following manner: participants were instructed to tighten their abdominal wall muscles by contracting and stiffening them without holding their breath. Various verbal cues were used, such as "tighten your stomach" or "stiffen your abdominals and your back." No direct verbal instruction was given to the participants to either hollow their abdominal wall or protrude it out. An additional facilitation of the active AB was performed. This involved having the clinician introduce slow and fast rolling movements about the participants' pelvis and torso in a rotational axis while the participants were requested to stiffen their torso sufficiently to resist these movements. These clinician-induced movements were introduced about the pelvis and done concurrently with verbal cueing until the subject was successfully able to offer a matched, isometric resistance sufficient to resist these perturbations. The use of such personalized verbal cues is a mainstay of the proprioceptive neuromuscular facilitation method of Knott and Voss [21]. It should be noted that the rolling perturbations were gentle and the matched resistance by the subject was only the intensity required to stiffen the spine and not more. It was necessary that all subjects maintained normal respiration while performing this AB maneuver sufficient to stiffen the spine against these perturbations.

Instrumentation

Throughout the study, a pressure mat (Tekscan Inc, Boston, MA) was used at the interface between the participants' posterior pelvis and lumbar spine, and the table. Pressure measurements were used to assess shifts in the center of pressure (CoP) for the participant's lumbar spine during performance of the ASLR. The sensor used is an ultrathin

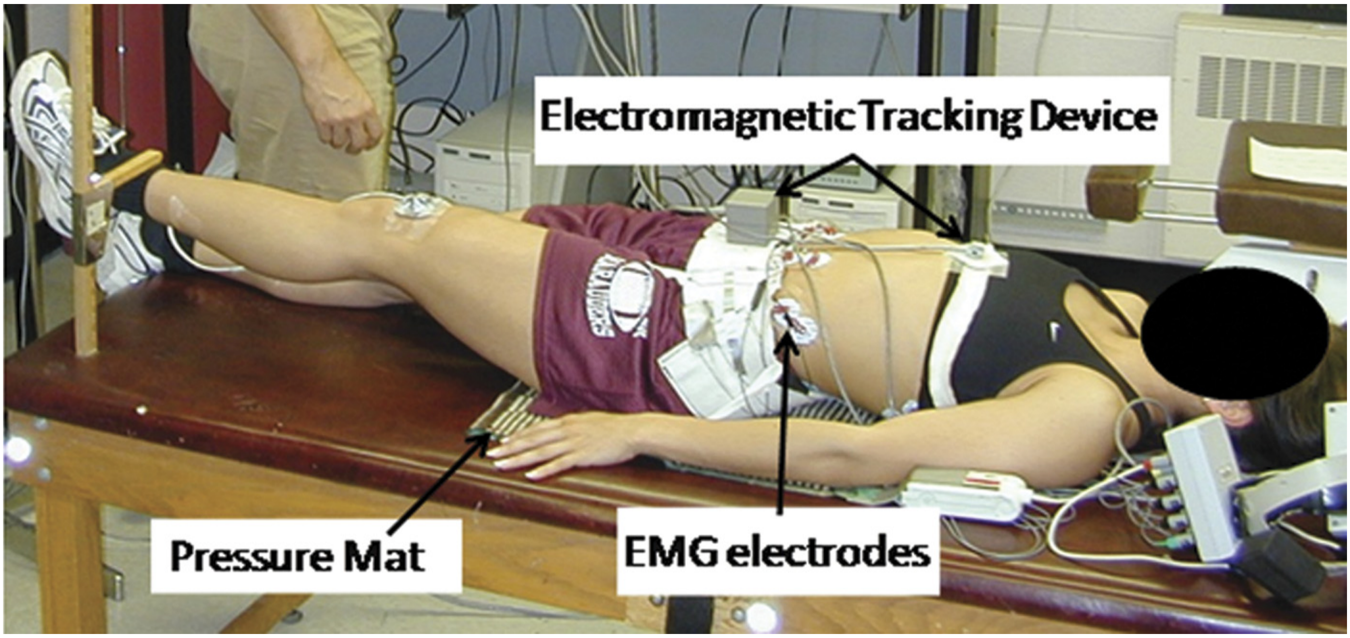

Figure 1. Picture of the participant's positioning at the point of maximum hip flexion during the active straight leg raise test.

(0.004 inch, 0.10 mm) flexible Mylar sheet containing a printed circuit. The sensor mat had 2016 individual sensing elements or cells organized in a 42 × 48 array. Before the study, the pressure mat was calibrated up to 200 PSI (equal to 1379 kPa) using a uniform pressure applicator. Horizontal displacement of the CoP was used as a surrogate measure for axial rotation of the lumbar spine. The maximum range (farthest left to farthest right) of movement was compared between the ASLR with and without AB. This approach was used to quantify the rolling movement of the torso that some clinicians try to palpate or observe [22].

Direct measurement of lumbar spine rotation about 3 orthogonal axes was performed using a 3Space ISOTRAK electromagnetic tracking instrument (Polhemus Inc, Colchester, VT). This instrument consists of a single transmitter that was strapped to the pelvis above the pubis and a receiver strapped across the ribcage, over the xiphoid process. Thus, the position of the ribcage relative to the sacrum was measured (lumbar motion).

Fourteen channels of EMG were collected from electrodes placed over the following muscles bilaterally: rectus abdominis (RA), external oblique (EO), internal oblique (IO), latissimus dorsi (LD), thoracic erector spinae (longissimus thoracis and iliocostalis at T9), and lumbar erector spinae (longissimus and iliocostalis at L3); also, right-side gluteus medius and gluteus maximus were recorded. The skin was shaved and cleansed with a 50% water and 50% ethanol solution. Ag-AgCl surface electrodes were positioned with an interelectrode distance of approximately 2.5 cm. The EMG signals were amplified and the analog signals were digitally converted with a 12-bit, 16-channel analog-to-digital converter at 1024 Hz. Each participant performed maximal isometric voluntary contractions (MVC) of each measured muscle for normalization (after Brown et al [23]). For the abdominal muscles, each participant, while in a sitting position and manually resisted by a research assistant, produced a maximal isometric flexor moment followed sequentially by a right and left lateral bend moment, and then a right and left rotational moment. For the erector spinae and gluteus maximus muscles, a resisted maximum extension in the Biering-Sorensen position was performed. The LD MVCs were conducted in a standing position using manually resisted LD pull-down maneuvers. The gluteus medius was targeted with resisted side-lying hip abduction (ie, "the clam"). Participants lay on their left side with the hips and knees flexed to 90°. Keeping their feet together, they abducted their right thigh to horizontal, and a research assistant restricted further movement. The MVC task protocol took about 20 minutes per participant, which allowed for sufficient rest to minimize any fatigue.

The EMG signals collected during the braced and unbraced ASLR were full-wave rectified and low-pass filtered with a second-order Butterworth filter and normalized to the maximum amplitude obtained from the similarly treated MVCs. A cutoff frequency of 2.5 Hz was used to mimic the frequency response of the torso muscles [24].

Spine Model for Estimation of Muscle and Spine Stiffness

Although a brief description of the modeling process is given here, readers who would like a more comprehensive description with mathematical rigor are recommended to read the previous literature, which outlines the process in more detail [12,19]. First, the spine was assumed to be in a posture that was close to neutral, at least for the purposes of assuming that passive tissue forces would not contribute substantial stiffness or bending torques. Next, the low-pass filtered EMG

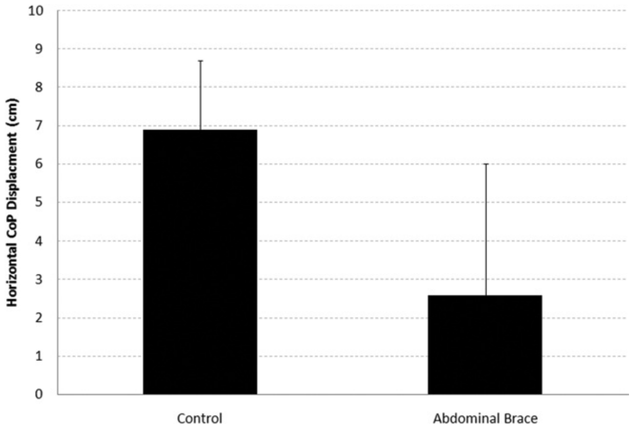

Figure 2. Horizontal displacement of the lumbar spine and pelvis center of pressure (CoP) during the active straight leg raise test with and without (control) abdominal bracing. A statistically significant difference was observed ($P < .0125$).

signals from the RA, EO, IO, LD, and both levels of erector spinae, together with the lumbar spine angles measured using the 3Space, were entered into an anatomically detailed spine model representing 118 muscle elements as well as lumped passive tissues, spanning the 6 lumbar joints (T12-L1 through L5-S1). Muscle lengths were measured as the distance between attachment points; for those muscles with curving lines of action, nodal points along the path were used. Muscle force and stiffness were calculated as a function of the estimated number of attached crossbridges, based on muscle activation, physiologic cross-sectional area, and stress and length using the distribution moment method [19]. Muscle geometry, force, and stiffness were used to quantify the rotational stiffness of the lumbar spine (as per Potvin and Brown [17]) about each of 18 degrees of freedom (6 lumbar joints and 3 orthopedic axes at each joint). The stiffness values were averaged across the 6 lumbar joints for each orthopedic axis; only the stiffness levels about the axial rotation axis are presented here.

Statistical Analysis

Lumbar spine stiffness, lumbar rotational motion, and muscle activation levels were computed for an approximately 1-second period at peak hip flexion during the ASLR test, and CoP displacement was measured as indicated in the previous section. These variables were compared between the ASLR with and without AB using a single-factor repeated measures analysis of variance with an α level of 0.05. Regression analysis revealed the dependence of horizontal CoP displacement on rotational stiffness.

RESULTS

CoP Movement

AB significantly reduced the lateral CoP movement (indicative of horizontal trunk rotational motion) compared with the control trial (no bracing) during ASLR from 6.9 to 2.6 cm ($P < .0125$; Figure 2).

Lumbar Axial Rotation

Lumbar axial rotation was significantly different between the ASLR with and without AB ($P = .02$; 5.4° without AB; 2.2° with AB; Figure 3).

Muscle Activity

All recorded muscles had average activation levels of less than 10% MVC during the ASLR without AB. All muscles displayed increases in average activation level when adding AB to the ASLR, and these differences were statistically significant ($P < .05$) for all muscles except the gluteus maximus and medius (Figure 4). The highest activation levels during the ASLR with AB were recorded in the right and left IO (approximately 22% MVC in both), and activation levels greater than 10% MVC were also documented in the right and left RA and EO, as well as in the right LD.

Lumbar Spine Stiffness

Lumbar spine stiffness about the axial rotation axis increased (more than doubled; $P < .002$) during the AB condition, relative to the control condition (Figure 5). Regression analysis showed that horizontal CoP movement was inversely related to spine stiffness ($r = -0.6$; Figure 6).

DISCUSSION

The results from the current investigation illustrate that AB significantly reduces CoP movement and lumbar spine rotational motion while increasing spine rotational stiffness during the ASLR. Interestingly, regression analysis revealed an expected negative correlation, but scatter of participant data points suggests that different participants used slightly different strategies. Thus using CoP movement under the pelvis

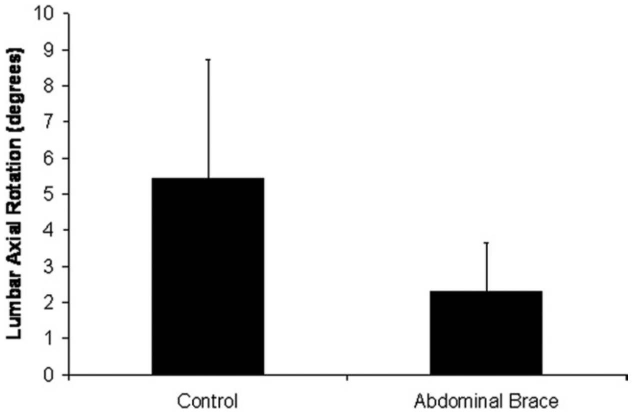

Figure 3. Lumbar axial rotation during the active straight leg raise test with and without (control) abdominal bracing. A statistically significant difference was observed ($P = .02$).

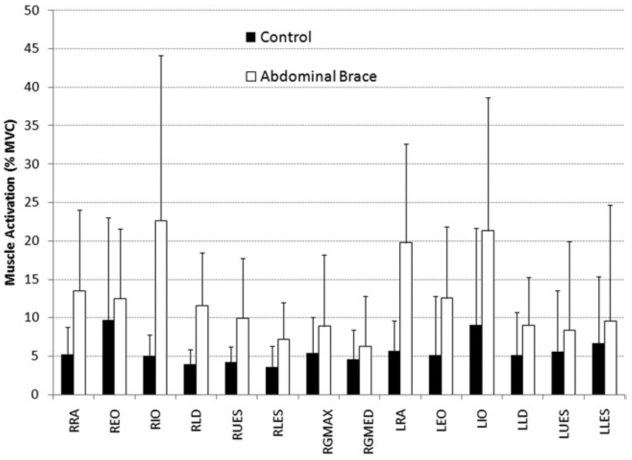

Figure 4. Average electromyographic activation levels recorded at peak hip flexion during the active straight leg raise test with and without (control) abdominal bracing. LEO, left external oblique; LIO, left internal oblique; LLD, left latissimus dorsi; LLES, left lower erector spinae; LRA, left rectus abdominis; LUES, left upper erector spinae; MVC, maximal voluntary contraction; REO, right external oblique; RGMAX, right gluteus maximus; RGMED, right gluteus medius; RIO, right internal oblique; RLD, right latissimus dorsi; RLES, right lower erector spinae; RRA, right rectus abdominis; RUES, right upper erector spinae.

alone appears to be clinically limited as it is only roughly coupled with stiffness. The ASLR test has previously been hypothesized to assess lumbopelvic and, in particular, SI stability during sagittal plane motions. The results of this study suggest that this test is also strongly associated with lumbar spine stability involving control of lumbar axial rotation (transverse plane) motions. Previous studies have suggested that pain during the ASLR that is reduced by AB is most likely of SI origin [2,3]. Results from this study suggest this interpretation may need to be refined to include the possibility of lumbar spine–related disease. Because AB involves stiffening the lumbar spine, pain that is reduced by AB could be of lumbar, SI, or pelvic origin when stability is lacking. Clinically it is important to appreciate that this test is not specific to the pelvis, as it could indicate a lumbar pain generator.

There is little related literature for comparison to these results. Although several reports have addressed the ASLR test as an indicator of pelvic instability and related pain—for example, restricting pelvic rotation has been shown to reduce pelvic pain in a patient population [1]—no previous attempts to specifically assess lumbar movement patterns and biomechanics during the test have been documented.

Activation levels increased in all recorded muscles when adding the AB to the ASLR; however, these increases were not statistically significant in the gluteus maximus or medius. This indicates that the AB may not directly (through muscle attachments) facilitate the stabilization of the pelvis; still, the significant increases in abdominal muscle activity may serve to stabilize the pelvis through the generation of intra-abdominal pressure and pelvic floor compression [7,8]. It has been previously documented [5,6], and confirmed here, that AB through light coactivation (ranging here between 13% and 22% MVC) serves to stiffen and stabilize the lumbar column.

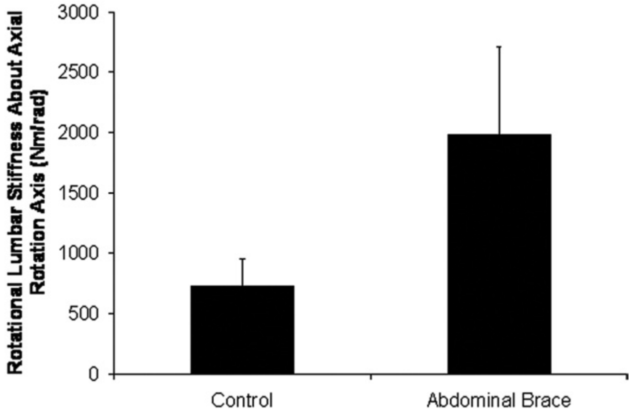

Figure 5. Lumbar rotational stiffness about the axial rotation axis during the active straight leg raise test with and without (control) abdominal bracing. A statistically significant difference ($P < .002$) was observed.

Several limitations impact the interpretation of the results presented here. This is a preliminary biomechanical study of the ASLR as modified by AB. No attempt to distinguish results in acute or chronic lower back pain patients or in asymptomatic individuals was attempted. Well-balanced muscular contraction will not only serve to stiffen the spine but will also increase its loading. The levels of muscular activation that served to stiffen the spine in this healthy population were relatively low and most likely would not create a risk for tissue damage as a result of excessive loading. It is important, however, to consider with a clinical population that pain and tissue tolerance levels may be reduced, and muscular activation levels may need to be increased to achieve a stiffening effect similar to that demonstrated here. It is thus imperative that a full clinical assessment and consid-

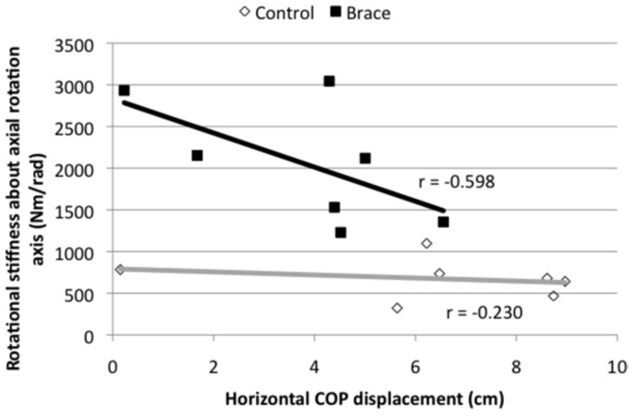

Figure 6. Regression of rotational stiffness with horizontal center of pressure (CoP) displacement in the control and braced condition.

erations of the mechanisms of pain and dysfunction (eg, compressive intolerance versus instability) are undertaken before a rehabilitation strategy is selected. Muscle coordination is certainly an issue because unbalanced or poorly chosen activation patterns have the potential to compromise stability [10].

The technique of performing an active AB is very simple. The goal is for the patient to functionally stiffen their spine while maintaining normal respiration. Verbal cues are used such as "tighten your stomach" or "stiffen your abdominals and back." No verbal cue about drawing the abdomen in or protruding it out are offered. Once the subject has attempted to actively "brace," then slow perturbations in the transverse plane are introduced. At first the patient is encouraged to allow them to occur, then he or she is instructed to maintain a locked position of the torso, spine, and pelvis against the clinician's resistance. The perturbations are in a rolling direction and are introduced gently.

CONCLUSION

The ASLR procedure can serve as a test for lumbar spine stiffness, at least in the axial rotation axis. Furthermore, AB reduced lumbar spine axial rotation, which suggests, and is supported by prior investigations [5,6], that AB may be a suitable countermeasure for patients whose pain is induced by excessive motion of the lumbar spine or pelvis. This will require further study comparing patients with pain to asymptomatic patients. Because the ASLR has been shown to be a sensitive measure of lumbar stiffness and therefore stability, future work may be directed toward assessing whether stability as measured with the ASLR test predicts motor control during other commonly prescribed training exercises.

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