Motor Control Patterns During an Active Straight Leg Raise in Pain-Free Subjects

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Pelvic girdle pain (PGP) is common during pregnancy, with 72% to 84% of pregnant women reporting symptoms in this region. For most this is self limiting, resolving within 3 months postpartum. However, in 7% to 10% of cases symptoms become chronic, persisting beyond 2 years.4–6 This condition is not limited to pregnancy, with other etiologies such as trauma also responsible for the development of chronic PGP.7,8

The underlying mechanisms that drive chronic PGP are complex and multifactorial. These may include hormonal and genetic factors, neurophysiological factors such as peripheral or central sensitization, pathoanatomical changes and biomechanical factors, and psychosocial influences to varying degrees.9 Recently research has focused on alterations of motor control (MC) as a potential mechanism for an ongoing peripheral drive of symptoms in chronic PGP. Evidence for the effectiveness of a motor learning approach in the management of chronic PGP supports that MC deficits may underlie some of these disorders.

Several studies have documented alterations of MC in PGP subjects (Table 1).8,10,12–14 Altered MC patterns could contribute to the maintenance of a chronic pain state via mechanical provocation of pain sensitized structures within the pelvis. An interesting outcome from some of these investigations has been the documentation of changes in the function of multiple body systems. Alterations of MC in response to the primary musculoskeletal disorder of PGP have been linked to changes in function of the respiratory system.8 There is also a link between changes in pelvic floor (PF) function with changes in the control of continence.8,14 These findings should not be surprising given that the lumbopelvic muscles, diaphragm, and PF are involved in assisting lumbopelvic stability, as well as controlling respiration, intra-abdominal pressure (IAP), and continence. To date, no study has investigated these systems in detail during the active straight leg raise (ASLR).

The aim of this study was to investigate MC strategies employed by pain-free subjects during low level load transference through the pelvis. The ASLR is a valid and reliable test for assessing load transference through the pelvis in PGP subjects.8,15–18 The methodology included simultaneous observation of trunk muscle activation, intraabdominal pressure (IAP), and intrathoracic pressure (ITP), variables not measured in previous work in this area.8,10 Patterns of MC related to lifting one leg versus the other were compared to elucidate neuromuscular system coordination during an ASLR. It was hypothesized that pain-free subjects would demonstrate a local motor strategy with minimal change in IAP.

Study Design. Repeated measures.

Objective. To investigate motor control (MC) patterns of normal subjects during the low level physical load of the active straight leg raise (ASLR).

Summary of Background Data. Aberrant MC patterns, as observed with the ASLR test, are considered to be a mechanism for ongoing pain and disability in subjects with chronic musculoskeletal pelvic girdle pain. These patterns may not only affect the provision of lumbopelvic stability, but also respiration and the control of continence. Greater understanding of MC patterns in pain-free subjects may improve the management of pelvic girdle pain.

Methods. Fourteen pain-free nulliparous women were examined during the ASLR. Electromyography of the anterior abdominal wall, right chest wall and the anterior scaleni, intraabdominal pressure (IAP), intrathoracic pressure (ITP), respiratory rate, pelvic floor kinematics, and downward leg pressure of the nonlifted leg were compared between a left and right ASLR.

Results. There was greater activation of oblique internus abdominis and oblique externus abdominis on the side of the ASLR. The predominant pattern of activation for the chest wall was tonic activation during an ipsilateral ASLR, and phasic respiratory activation lifting the contralateral leg. Respiratory fluctuation of both IAP and ITP did not differ lifting either leg. The baseline shifts of these pressure variables in response to the physical demand of lifting the leg was also the same either side. There was no difference in respiratory rate, pelvic floor kinematics, or downward leg pressure.

Conclusion. Pain-free subjects demonstrate a predominant pattern of greater ipsilateral tonic activation of the abdominal wall and chest wall on the side of the ASLR. This was achieved with minimal apparent disruption to IAP and ITP. The findings of this study demonstrate the plastic nature of the abdominal cylinder and the flexibility of the neuromuscular system in controlling load transference during an ASLR.

Key words: active straight leg raise, motor control, intraabdominal pressure. Spine 2009;34:E1–E8
The skin was lightly abraded and cleaned so that impedance was \(<5 \text{k} \Omega\).\textsuperscript{26} Disposable Ag/AgCl electrodes (ConMed Corp., Utica, NY) were placed \textit{in situ} with an intraelectrode distance of 2.5 cm. Two Octopus Cable Telemetric units (Bortec Electronics Inc., Calgary, Canada) were used, one for each side of the body, earthed to the anterior superior iliac spine of the corresponding side. Data were sampled at 1000 Hz, at a bandwidth of 10 to 500 Hz, with a common mode rejection ratio of \(>115 \text{ dB} \) at 60 Hz, and preamplified and amplified at an overall gain of 2000.

Intraabdominal pressure and ITP were recorded with a custom made silicone nasogastric catheter (Dentsleeve International Ltd., Mississauga, Canada). Saline solution was passed at high pressure through tiny lumen in the catheter. Changes in the rate of flow through the lumen that occur in response to changes in pressure were monitored using custom built pressure transducer equipment. The system was calibrated against pressure measurements at known depths of water. Correct location of the catheter in the thorax and abdomen was confirmed with opposite pressure changes in both channels during respiration.\textsuperscript{27}

To monitor any compensatory downward pressure of the leg not being lifted, an inflated pad linked to a pressure transducer was placed under the heel. Respiratory, EMG, and pressure variables were collected simultaneously on a computer running LabVIEW v6.1 (National Instruments, Austin, TX). Concurrently kinematics of the PF were monitored using a Capesess SSA-220A ultrasound unit (Toshiba Corp., Tochigi, Japan).\textsuperscript{8,28–31} The probe was positioned transabdominally, angled inferiorly, to view the bladder. Trials were recorded to digital video.

### Data Collection and Processing

For normalization 3 seconds of EMG data were collected for 3 repetitions of a crook lying double leg raise with cervical flexion as a submaximal reference contraction.\textsuperscript{21,32–34} The average root mean square (RMS) was used. Data were then collected during 60 seconds in resting supine. Initially the subjects were asked to cough, producing movement on the ultrasound which acted as a marker to synchronize PF video with the rest of the data. Then data were collected during the ASLR. Approximately, 5 seconds after coughing, subjects were asked to raise their leg 10 cm. After approximately 45 s, the subjects were then instructed to lower their leg and data collection was ceased a further 10 s later. This was repeated twice per leg to allow for repeatability analyses.

A custom designed data processing program was used to prepare the data for analysis. The EMG was inspected for contamination by heartbeat and other artifact. Data were then demeaned, band pass filtered from 4 to 400 Hz with a fourth order Butterworth filter with zero lag and normalized. The RMS for 500 milliseconds during the middle of the inspiratory and expiratory phases of 3 breath cycles was calculated. This allowed investigation of phasic EMG changes in relation to respiration \textit{versus} tonic EMG changes in response to physical loading related to the ASLR. Pressure change over the breath cycle was calculated for both IAP and ITP during each breath cycle by subtracting the minimum from the maximum pressure value during that breath. This allowed investigation of the normal phasic change in these measures associated with respiration. Pressure change related to physical loading was ascertained by calculating a baseline shift. Baseline shift equaled the

### Materials and Methods

#### Subjects

Fourteen pain-free, nulliparous women were recruited from the Perth metropolitan region (average age 28.9 ± 5.9 years, average BMI 23.0 ± 2.1 kg/m\(^2\), average adductor strength\textsuperscript{19} 167.1 ± 35.4 N). Exclusion criteria were history of a musculoskeletal pain disorder in the last 6 months, surgery in the last year, current neurologic or inflammatory disorders, or a history of a significant respiratory disorder. Written informed consent was obtained from all subjects. Ethical approval was granted by the Human Research Ethics Committee of Curtin University of Technology.

#### Equipment and Setup

Respiratory, electromyographic (EMG), pressure, and kinematic data were collected concurrently during the ASLR. The phase of respiration was recorded \textit{via} the pneumotach of a Benchmark Pulmonary Exercise System (P.K. Morgan Instruments, Inc., Andover, MA), which was modified with an external output.

Electromyographic data were collected from the following muscles:

- Bilateral rectus abdominis (RA): 1 cm above and 2 cm lateral to the umbilicus.\textsuperscript{20}
- Bilateral oblique externus abdominis (EO): just below the rib cage on a line connecting the inferior costal margin with the contralateral public tubercle.\textsuperscript{20}
- Bilateral lower fibers of oblique internus abdominis (IO): just medially and inferior to the anterior superior iliac spine.\textsuperscript{20}
- The right chest wall (CW): at the sixth and seventh intercostal spaces, 2 cm lateral to the mid clavicular line.\textsuperscript{21–23}
- Bilateral anterior scalene (Sc): over the anterior Sc adjacent to the lower third point of a line between the mastoid and the sternal notch.\textsuperscript{24}
- Bilateral rectus femoris: mid way between the anterior superior iliac spine and the superior border of the patella\textsuperscript{25} (as a marker for when the leg was lifted, not otherwise analyzed).

#### Table 1. Findings of Altered Motor Control in Subjects With PGP

<table>
<thead>
<tr>
<th>Activity</th>
<th>Altered Motor Control Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>De Groot et al\textsuperscript{12} Hungerford et al\textsuperscript{13}</td>
<td>ASLR Standing hip flexion Increased bilateral EO activity Delayed onset of IO and multifidus bilaterally Delayed onset of gluteus maximus on the symptomatic side Early activation of biceps femoris on the symptomatic side</td>
</tr>
<tr>
<td>O’Sullivan et al\textsuperscript{8}</td>
<td>ASLR Decreased diaphragmatic excursion Altered respiratory patterns Descent of the PF Depression of the PF</td>
</tr>
<tr>
<td>O’Sullivan and Beales\textsuperscript{10} Pool-Goudzwaard et al\textsuperscript{14}</td>
<td>Voluntary PF Contraction Voluntary PF Maneuvers Increased PF activation</td>
</tr>
</tbody>
</table>

ASLR indicates active straight leg raise, EO, obliquus externus abdominis, IO, obliquus internus abdominis, PF, pelvic floor.
average minimum pressure value of the 3 breath cycles during an ASLR minus that of resting supine.

Respiratory rate (RR) was calculated from the respiratory traces during the ASLR. The average pressure exerted downward by the nonlifted leg was calculated over the breath cycle. Movement of the PF was obtained by capturing two frames of video: (a) slightly before and after the leg lift to ascertain bladder motion secondary to the ASLR, and (b) at the maximum and minimum points of excursion over each of the three breath cycles to observe motion in response to respiration. These frames were overlaid to measure the distance the PF moved.

Data Management and Analyses

Data from the 3 breath cycles were averaged and analyzed with a 2 (side: left ASLR, right ASLR) by 2 (respiration: inspiration, expiration) repeated measures analysis of variance. A separate model was constructed for each muscle. Paired t tests were used for post hoc analyses. Intraabdominal pressure, ITP, RR, leg pressure, and the PF motion variables were compared lifting one leg versus the other with paired t tests. This was complimented with visual inspection of the motor patterns.

To examine consistency of the motor patterns intraclass correlation coefficients and corresponding 95% confidence intervals were calculated for all variables over 2 sequential leg lifts. Analysis was performed with SPSS 14.0 for Windows (SPSS Inc., Chicago, IL), with a critical P value of 0.05.

Results

Bilateral Lower Fibers of Obliquus Internus Abdominis

Activation of IO was greater during an ipsilateral ASLR compared with a contralateral ASLR (left IO: side P = 0.004; right IO: side P = 0.001) (Figure 1). Activation was tonic in nature (left IO: respiration P = 0.919; right IO: respiration P = 0.307), regardless of which side the ASLR was on (left IO: side by respiration P = 0.426; right IO: side by respiration P = 0.464) (Figure 1). This indicates a response in IO to the physical load of the leg lift which was not overtly influenced by the respiratory cycle. An example of this pattern is visible on the EMG trace in Figure 2.

Bilateral Obliquus Externus Abdominis

Visual examination of the EO EMG traces revealed the same pattern of greater tonic activation during an ipsilateral ASLR as the IO muscles (Figure 1 and 2). For the left EO this did reach statistical significance (side P = 0.028, respiration P = 0.418, side by respiration P = 0.886), whereas it did not for the right (side P = 0.068, respiration P = 0.442, side by respiration P = 0.204) (Figure 2).
Bilateral Rectus Abdominis

Activation of RA was no different performing a left or right ASLR (left RA: side \( P = 0.065 \); right RA: side \( P = 0.207 \)) (Figure 1). Although the main effect for respiration was significant for the left RA (respiration \( P = 0.049 \); side by respiration \( P = 0.877 \)) this was not supported by the post hoc tests (inspiration vs. expiration: \( P = 0.096 \)). There was no effect for respiration for the right RA (respiration \( P = 0.079 \), side by respiration \( P = 0.893 \)) (Figure 1). Visual inspection confirmed a very consistent pattern of equal tonic activation lifting either leg (Figure 2).

Right Chest Wall

Overall, activation at the right CW did not differ lifting either leg (side \( P = 0.111 \), respiration \( P = 0.073 \), side by respiration \( P = 0.743 \)) (Figure 3). Visual inspection of the EMG traces demonstrated some discrete patterns that may be confounding this analysis. The predominant pattern (8/14 subjects) was of phasic activity lifting the

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**Figure 2.** Demeaned and normalized EMG traces during a right ASLR. The spike at the beginning of the traces is a cough. Subject A, displays the typical pattern of increased IO activation on the ipsilateral side of the leg being lifted. Increased activation of the ipsilateral EO is also discernable. Activation of RA seems more symmetrical. All muscle activation seems primarily tonic in nature in response to lifting the leg. Right IO appearance of being clipped at the top is simply for scaling purposes to allow clear comparison.

**Figure 3.** Average (standard error of the mean) RMS EMG for the right CW and Sc muscles. Inset \( P \) values on graph are from post hoc \( t \) tests, denoting phasic activation of the Sc lifting either leg. (i, indicates inspiration, e, expiration, ASLR, active straight leg raise, CW, chest wall, Sc, anterior scalene, R, respiration).
contralateral leg, but a shift towards tonic activation lifting the ipsilateral leg (Figure 4). However, 2 subjects demonstrated predominant phasic activity lifting either leg, while 4 displayed predominant tonic activation lifting either leg (Figure 4).

**Bilaterial Anterior Scalene**
There was phasic inspiratory activation of both (left Sc: respiration $P = 0.024$; right Sc: respiration $P = 0.012$) lifting either leg (left Sc: side $P = 0.919$, side by respiration $P = 0.462$, right Sc: side $P = 0.902$, side by respiration $P = 0.043$) (Figure 3).

**Intraabdominal Pressure and Intrathoracic Pressure**
Respiratory fluctuation in IAP ($P = 0.372$) and ITP ($P = 0.266$) were the same lifting either leg (Figure 5). There was a slight rise in IAP from a resting supine baseline level during an ASLR, but this IAP baseline shift was not significantly different ($P = 0.17$) performing a left or right ASLR (Figure 5). There was no difference for the baseline shift in ITP ($P = 0.712$) lifting either leg (Figure 5).

**Respiratory Rate**
RR was comparable during either ASLR (left ASLR: 15.6 (1.3) breaths/min; right ASLR: 15.0 (1.3) breaths/min; $P = 0.414$).

**Pelvic Floor Movement**
There was no difference in PF movement during an ASLR lifting either leg ($P = 0.1$), with a mean standard error of the mean, downward movement of 3.7(0.5) mm lifting the left leg, and 3.4 (0.6) mm lifting the right. Interestingly, 1 subject elevated the PF during the ASLR of either side, while 3 subjects displayed depression lifting one side and elevation lifting the other. Respiratory motion of the PF was comparable lifting either leg (left ASLR: 2.7 (1.0) mm; right ASLR: 4.0 (1.0) mm; $P = 0.801$).

**Contralateral Leg Downward Pressure**
Downward pressure with the nonlifted leg was comparable during either ASLR (left ASLR: 59.04 (7.65) N; right ASLR: 57.47 (8.04) N; $P = 0.801$).

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**Figure 4.** In these EMG traces of demeaned and normalized EMG, Subject B, demonstrates the typical pattern of tonic right CW activation lifting the contralateral leg compared with phasic activation lifting the ipsilateral leg. Subject C, demonstrates phasic activation maintained lifting either leg. Subject D, demonstrates predominant tonic activity lifting either leg. (ASLR indicates active straight leg raise, CW, chest wall).
**Consistency of Patterns**

Repeatability over two trials was good to very good for all variables except for the baseline shift of IAP which displayed more variability (Table 2).

**Discussion**

This study documents motor patterns observed in pain-free, nulliparous female subjects during a low level physical load of an ASLR in supine. The findings were consistent with the hypothesis of a predominant local motor strategy with minimal change in IAP.

**Muscle Activation**

The abdominal wall demonstrated a pattern of increased activation in IO and EO on the side of the ASLR (Figure 1). This was most pronounced in IO (Figure 2), representing a consistent strategy to recruit muscles local to the pelvis, in an apparent role to assist efficient load transference. This corresponds with other in vivo EMG studies in pain-free subjects which have reported an important role for IO in providing pelvic stability in various standing positions and during sitting. In contrast to our findings, a symmetrical pattern of EO activation in pain-free subjects during an ASLR has been reported. That study had 13 pain-free subjects who were between 12 and 40 weeks of pregnancy. This suggests the neuromuscular system may adopt a different MC strategy for an ASLR during pregnancy.

Biomechanical models have been generated to explain the muscular systems contribution to enhancing pelvic stability. This resulted in the description of muscular slings which may contribute to pelvic stability by exerting compressive force across the pelvis. Purportedly the oblique slings traverse diagonally across the pelvis giving them a mechanical advantage to provide this compression. This has been supported by in vivo EMG studies, in particular the report of activation of gluteus maximus and latissimus dorsi on opposite sides during walking and resisted torso rotation. The present study did not demonstrate coactivation of IO and EO on opposite sides as might be predicted by the model of the anterior oblique sling, but rather a MC pattern dominated by greater activation ipsilateral to the ASLR (Figure 1 and 2). This suggests the pattern of recruitment of the abdominal muscles is based on the nature of the task.

![Figure 5. Pressure changes (mean, standard error of the mean) for IAP and ITP. Measurements did not differ over the respiratory cycle and baseline shift lifting either leg. (IAP indicates intra-abdominal pressure, ITP, intrathoracic pressure, ASLR, active straight leg raise).](image)

**Table 2. Consistency of Motor Patterns Over Two Trials for the Left and Right ASLR, Expressed via ICC Values and Their 95% CIs**

<table>
<thead>
<tr>
<th></th>
<th>Left ASLR: ICC (95% CI)</th>
<th>Right ASLR: ICC (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle activation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAP-breath cycle</td>
<td>Highest: 0.987 (0.959–0.996)</td>
<td>Highest: 0.98 (0.937–0.993)</td>
</tr>
<tr>
<td>ITP-breath cycle</td>
<td>Lowest: 0.895 (0.671–0.966)</td>
<td>Lowest: 0.775 (0.299–0.928)</td>
</tr>
<tr>
<td>IAP-baseline shift</td>
<td>Median: 0.948</td>
<td>Median: 0.889</td>
</tr>
<tr>
<td>ITP-baseline shift</td>
<td>0.924 (0.764–0.976)</td>
<td>0.985 (0.955–0.995)</td>
</tr>
<tr>
<td>RR</td>
<td>0.405 (0–0.809)</td>
<td>0.267 (0–0.875)</td>
</tr>
<tr>
<td>PF movement–leg lift</td>
<td>0.710 (0.969–0.970)</td>
<td>0.896 (0.967–0.967)</td>
</tr>
<tr>
<td>PF movement–breath cycle</td>
<td>0.914 (0.732–0.972)</td>
<td>0.881 (0.960–0.962)</td>
</tr>
<tr>
<td>Contralateral leg pressure</td>
<td>0.954 (0.856–0.956)</td>
<td>0.954 (0.829–0.992)</td>
</tr>
</tbody>
</table>

**ICC** indicates intraclass correlation coefficient, CI, confidence interval, ASLR, active straight leg raise, IAP, intraabdominal pressure, ITP, intrathoracic pressure, RR, respiratory rate, PF, pelvic floor.

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at hand as much as any predetermined neuromuscular strategy.

The results of the right CW support this idea of a change in activation pattern related to the specific demands of the task. The majority of the subjects demonstrated a shift from phasic activity relative to respiration while performing a contralateral ASLR, to tonic activation with an ipsilateral ASLR (Figure 3). However, not all subjects displayed this pattern (Figure 4), highlighting the need to consider individual variation when observing MC patterns. The observed individual differences could have resulted from a number of factors, such as heterogeneity of cardiovascular fitness levels, which could warrant further investigation.

Gross patterns of muscle activation recorded in this study could potentially over simplify neuromuscular function during the ASLR. From a physiologic perspective it must be recognized that certain muscle groups may simultaneously attend to respiratory demands and challenges to lumbopelvic stability. However, gross muscle patterns are of interest as they are potentially detectable by clinicians, and as such may be useful from a rehabilitation perspective.

Intraabdominal Pressure and Intrathoracic Pressure
Subjects in this study were able to lift their leg without disturbing IAP and ITP fluctuations associated with respiration (Figure 5). The magnitude of the fluctuation for IAP was similar to that reported during quiet breathing. Additionally, there was only a slight increase in IAP associated with the ASLR (Figure 5). These findings support the notion that the ASLR in pain-free subjects represents a low level physical load. Most subjects in this study achieved this with a pattern of tonic abdominal and chest wall muscle activation ipsilateral to the side of the ASLR. This highlights the plasticity of the system in attending to physical loading without affecting respiration. Similar findings have been observed in subjects performing an isometric lifting task, where a low increase in IAP was observed, whereas the abdominal muscles attended to stability and the chest wall helped maintain ventilation.

There was some variability in the baseline shift of IAP lifting either leg (Table 1). This was despite consistent tonic patterns of motor system activation of the abdominal wall, consistent fluctuation of IAP and ITP in relation to respiration, and a fairly consistent change in baseline shift of ITP. This may reflect a limitation of this study in not being able to directly monitor all the muscles which produce and control IAP, namely, the PF, diaphragm, and transversus abdominis. Alternatively, it may reflect flexibility in the neuromuscular control system with regard to this variable under low load conditions.

Pelvic Floor Movement
Movement of the PF measured transabdominally may represent a combination of bladder movement and movement of the abdominal wall against the probe. This is not problematic as these 2 dimensions reflect adaptation of the abdominal pressure cylinder related to changes in IAP and muscle activation. Also the use of transabdominal ultrasound to measure PF motion is supported by a positive correlation with transperineal ultrasound measurement.

Minimal movement of the bladder was observed during the ASLR on either side. This is similar to the findings in pain-free subjects in our previous study, and contrasts to the bladder depression observed in a subgroup of chronic PGP subjects during an ASLR and the inability of subjects from the same subgroup to elevate the PF with a conscious PF contraction.

The level of activation of the PF musculature can not be inferred from movement observed on ultrasound. In a few of the subjects though, lifting of the PF was observed during the ASLR. This may denote a more active role of the PF in these subjects during an ASLR. Biomechanical models certainly support the role of the PF in the provision of pelvic stability. Further in vivo studies directly measuring PF activation are warranted to investigate the role the PF in contributing to pelvic stability.

Conclusion
This study investigated MC patterns during an ASLR in pain-free subjects. From a MC perspective the predominant pattern was greater ipsilateral tonic activation of the abdominal wall and chest wall on the side of the ASLR. This is achieved with apparently minimal disruption to IAP and ITP fluctuations related to respiration, and with a minimal baseline shift in IAP. These findings highlight the flexibility of the neuromuscular system in controlling load transference during an ASLR, and the plastic nature of the abdominal cylinder.

Key Points
- Aberrant MC patterns are thought to be a mechanism for ongoing pain and disability in chronic PGP, and affect multiple body systems besides the provision of lumbopelvic stability such as respiration and continence.
- This study documents multiple facets of the MC strategies in pain-free subjects during the ASLR, which may improve understanding of MC in subjects with chronic PGP.
- The main finding of this study was that subjects demonstrated a predominant pattern of greater ipsilateral tonic activation of the abdominal wall and chest wall on the side of the ASLR.
- The findings of this study demonstrate the plastic nature of the abdominal cylinder and the flexibility of the neuromuscular system in controlling load transference during an ASLR.
References


