Hip and Trunk Muscle Timing During Selected Movement Tasks: An Electromyographic Analysis

Michael C. Rabel (mcrabel@umes.edu), Frank Rosenthal, Jaclyn Smith, Heather Bennett, University of Maryland Eastern Shore, USA

ABSTRACT

Purpose: The aim of this study was to (1) identify the muscle firing pattern during the prone hip extension (PHE) and supine hip abduction (SHA) movement tasks and (2) examine the difference in intermuscular timing between the first muscle to fire and all remaining muscles, for each movement task.

Methods: The intermuscular timing of muscle activation, based on an activation level of greater than 3 standard deviations beyond base activity, for specific trunk and lower extremity muscles were examined by surface Electromyography (EMG) in twenty-three healthy, active, pain free subjects (mean age ± SD, 27.2 ± 4.5 years). Data were collected from the dominant lower extremity of all subjects (12 males, 11 females). Computerized voice activation commands were used to record and synchronize the movement tasks and standardize the protocol. Mean timing and activation levels were identified for each muscle. A 1-sample t test was used to determine which muscles were activated later than the first muscle to fire.

Results: Differences in intermuscular timing were identified for both movement tasks. PHE required trunk muscle activation prior to lower extremity muscle activation. The contralateral erector spinae was activated significantly earlier than the gluteus maximus (P=.004). A different pattern was identified for SHA. Trunk muscles, on the side of the moving limb, were activated before the muscles responsible for moving the limb. In addition, all of the trunk muscles were activated significantly later than the hip musculature (P≤.019). The hip muscles were the first to fire with the tensor fascia latae activated earliest.

Conclusions: These movement tasks required different trunk and hip activation patterns. During PHE, a less stable pelvic position may have contributed to the earlier trunk muscle activation and a firing pattern with the gluteus maximus last in the sequence. The reverse occurred during the SHA movement task. A better understanding of muscle timing and activation patterns can assist clinicians in assessing patients and developing more effective rehabilitation programs.

Keywords: Electromyography, Muscle Timing, Firing Patterns

INTRODUCTION

The sidelying hip abduction (SHA) and prone hip extension (PHE) maneuvers are commonly used to screen patients with hip and/or low back dysfunction. Understanding the normal hip and trunk muscle firing patterns, during these movement tasks, can assist in identifying motor control issues and appropriate interventions. Differences in muscle firing patterns have been linked to low back pain (LBP) and it is suggested that clinicians should measure not only the strength, but also the sequence of trunk muscle activation (D'Orazio, 1993; Greenman, 2003).

Dysfunction of the gluteus medius (GMed) has been linked to LBP and is commonly addressed during the rehabilitation process (Ekstrom, Donatelli, & Carp, 2007). When selecting an exercise to target a specific muscle (GMed), the clinician must consider both the effectiveness of the exercise to recruit the primary muscle and the relative activity levels of any secondary musculature, such as the tensor fascia latae (TFL). Specific patterns of muscle recruitment have been proposed based on clinical observations. However, research on the topic is limited and conflicting.

In healthy individuals, activation of the transversus abdominus and multifidus consistently preceded that of the more distal muscles during active extremity motion (Hodges & Richardson, 1997, 1998). During PHE, Vogt and Banzer (1997) showed that the ipsilateral erector spinae is recruited prior to the hamstrings. Similarly, several studies have
shown the gluteus maximus (GMax) to be the muscle activated last during hip extension while prone (Lehman, Lennon, Tresidder, Rayfield, & Poschar, 2004; Sakamoto, Teixeira-Salmela, de Paula-Goulart, de Morais Faria, & Guimaraes, 2009; Vogt & Banzer, 1997).

In contrast, it has been suggested that the prime movers of the hip are activated before the stabilizers. During the SHA task, the gluteus medius and tensor fascia latae were clinically observed to fire prior to the ipsilateral erector spinae (Greenman, 2003). Similar finding were observed with PHE. Even though the hamstrings fired first, there has been disagreement on the exact pattern of muscle recruitment and the results from subsequent studies have varied (Bullock-Saxton, Janda, & Bullock, 1994; Greenman, 2003; Sakamoto, et al., 2009). In addition, two studies directly concluded that there was no consistent pattern of muscle recruitment during PHE (Lehman, et al., 2004; Pitcher, Behm, & MacKinnon, 2008).

Pain and dysfunction of the trunk have a greater negative effect on trunk muscle co-activation and recruitment patterns than on strength (P. O'Sullivan, Twomey, Allison, Sinclair, & Miller, 1997; P. B. O'Sullivan, Phyty, Twomey, & Allison, 1997). With LBP, these aberrant firing patterns may lead to compensatory substitutions which reduces the ability of the stabilizing muscles to optimally perform (Danneels et al., 2002). Several authors agree that the most common pathologic substitution seems to be the delay in firing of the GMax in the PHE test, and of the GMed in the SHA test (Bruno & J., 2007; Bullock-Saxton, et al., 1994; Greenman, 2003). Hodges and Richardson (1998) concur and demonstrated that in patients with LBP, the normal proximal to distal muscle activation pattern was reversed.

Currently, there is a lack of definitive evidence for the normal firing patterns during lower extremity movement tasks in healthy subjects. Research has primarily focused on the level of muscle activation (recruitment) as opposed to muscle timing. Studies that have investigated activation patterns (timing) of hip and trunk musculature produced contradictory findings. Therefore, the purpose of this study was to (1) identify the muscle firing pattern during the PHE and SHA movement tasks and (2) examine the difference in intermuscular timing between the first muscle to fire and all remaining muscles during the same movement tasks.

METHODS

Subjects

The data were obtained from a group of 23 healthy physically active volunteers (12 males, 11 females; mean ± SD age, 27.2 ± 4.5 years; height, 171.4 ± 9.1 cm; body mass, 74.3 ± 20.4 kg; body mass index, 25.0 ± 4.9 kg/m²). Subjects were recruited from the student population and the local community. All were right leg dominant. The dominant lower extremity was tested in all subjects. Subjects were included if they were between 20 and 45 years of age, physically active, and able to perform the desired movement tasks. Subjects were excluded if they were pregnant or had given birth within the past 2 years, had a history of back or lower extremity surgery, had current symptoms related to the lumbar spine or current lower extremity pain. Subjects participating in competitive sports or high level strength training were also excluded. Inclusion and exclusion criteria were assessed with a questionnaire. All subjects gave their written, informed consent to participate in the study, which was approved by the University of Maryland Eastern Shore’s Institutional Review Board.

Protocol

Subjects attended 1 test session. During this time they were interviewed for demographic data, completed questionnaires, assessed for adequate motor control and range of motion, and oriented to the test protocol. All testing was performed on the dominant lower extremity. The testing procedure consisted of electrode placement, practice and familiarization, and movement task assessment.
General Practice Physical Activity Questionnaire

The GPPAQ provides a simple, four-level Physical Activity Index (PAI) reflecting an individual’s current physical activity level. The instrument is intended for adults (16-74 years of age) and is a simple tool, requiring 30 seconds to complete. The GPPAQ has been shown to have good face and construct validity (Khaw et al., 2006).

Electrode Placement

After walking around the perimeter of the room, subjects were prepared for electrode placement. Alcohol was used to cleanse the skin and reduce tissue impedance. Bipolar surface electrodes (Noraxon USA, Inc; Scottsdale, AZ) were placed on the appropriate muscles based on the EMG manufacturer guidelines (Konrad, 2006) and a basic understand of surface anatomy (Greenman, 2003; Kendall, 2005). Electrodes were Ag-AgCl pre-gelled with a diameter of 1cm and inter-electrode distance of 2 cm. The same examiner positioned the electrodes on all subjects. Each electrode was connected to a Noraxon Telemyo 2400T G2 transmitter (Noraxon USA, Inc; Scottsdale, AZ). The sampling rate was 1500 Hz. All raw myoelectric signals were pre-amplified (overall gain, 500). The common mode rejection ratio was >100 dB, the signal-to-noise ratio was <1 µV RMS baseline noise, and filtered to produce a bandwidth of 10-500 Hz.

For both movement tasks, the same trunk muscles were recorded on each side of the torso. The lumbar multifidus electrodes were placed 2cm lateral to the L5 spinous process. Lumbar ES electrodes were placed 4cm lateral to the L3 spinous process. The selected dominant hip muscles differed for each movement task. During PHE, the GMax electrodes were placed 4 cm inferior to the posterior superior iliac spine. The medial and lateral hamstring electrodes were placed at the mid-thigh level, between the gluteal fold and the femoral condyles. During SHA, the TFL electrodes were placed at the mid-point of an imaginary line between the greater trochanter and the anterior superior iliac spine (ASIS). The GMed electrodes were applied 2.5 cm posterior to the midpoint of the line bisecting the ASIS and greater trochanter. All electrodes were placed parallel to the fiber direction of the target muscle. Correct electrode placement was verified by EMG signal analysis (visual inspection) during the motion task under consideration. This information was also used to ensure that a true baseline was maintained at rest. A reference electrode was placed along the shaft of one of the ribs, right mid-axillary line.

Movement Tasks

During PHE, subjects were positioned on their stomach with their knees extended and ankles off the edge of the mat (FIGURE 1A). From this position, the subject performed maximal hip extension. The second motion under investigation was the SHA task. Subjects were positioned in left sidelying with the dominant leg in neutral, resting on a pillow, with the knee extended (FIGURE 1B). Subjects performed maximal hip abduction. Before data collection, each motion was demonstrated by a member of the research team. After a period of familiarization and corrective feedback, subjects performed 3 trials of each motion task. A standardized set of computer generated voice commands were used to synchronize the data collection process. Upon command, subjects moved into the desired position and held that position for 3 seconds. Subjects rested for 1 minute between trials. The aim of our study was to investigate muscle latency times at the beginning of each movement task. Therefore, only the concentric phase of the task was analyzed in order to better understand onset patterns.

FIGURE 1. Movements studied: (A) prone hip extension and (B) sidelying hip abduction.
Data Processing

Raw EMG data was converted from analog to digital at 1500 Hz. The raw signals were rectified, smoothed, and reduced for cardiac artifact. Activation of the different muscles was determined for each movement task. A muscle was considered to be activated when the signal surpassed the trigger level of 3 standard deviations beyond the baseline level at the beginning of the concentric phase of the motion. This method sets activation at a higher threshold and is considered to be a reliable technique (Bolgla, Malone, Umberger, & Uhl, 2010; Di Fabio, 1987). The point in time when each muscle reached this activity level was determined. These measures of time were averaged for each muscle during both movement tasks.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences, version 17.0 (SPSS Inc, Chicago, IL). These individual mean muscle onset times were averaged across the group to determine the overall mean onset time of each muscle. From this data, the firing patterns for the 2 movement tasks (PHE and SHA) were established. In order to examine the intermuscular timing differences, the relative activation of each muscle in relation to the first muscle to fire was determined. For each movement task, the muscle with the smallest activation value was subtracted from the other muscle activation values. A 1-sample t-test (2-tailed) was performed to examine which latencies were significantly different from the first muscle to be recruited, or the zero point.

RESULTS

Muscle Activation

The muscle firing pattern for PHE is summarized in Table 1. During this movement task, the proximal musculature on the contralateral side of the trunk was recruited prior to the lower extremity muscles. The erector spinae (CES) was the first muscle to fire while the GMax was the last muscle in the sequence to become active during lower extremity elevation in this position.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Mean Onset Time</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contralateral Erector Spinae</td>
<td>728</td>
<td>233</td>
</tr>
<tr>
<td>Contralateral Multifidus</td>
<td>751</td>
<td>178</td>
</tr>
<tr>
<td>Ipsilateral Biceps Femoris</td>
<td>755</td>
<td>177</td>
</tr>
<tr>
<td>Ipsilateral Semitendinosus</td>
<td>759</td>
<td>262</td>
</tr>
<tr>
<td>Ipsilateral Multifidus</td>
<td>774</td>
<td>284</td>
</tr>
<tr>
<td>Ipsilateral Erector Spinae</td>
<td>823</td>
<td>264</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>889</td>
<td>180</td>
</tr>
</tbody>
</table>

* Data are in millisecond (n=23)

The muscle activation sequence during SHA is summarized in Table 2. During this test, the extremity musculature was recruited prior to all of the trunk muscles. Further, the trunk muscles on the same side of the moving lower extremity were before the contralateral trunk musculature.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Mean Onset Time</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensor Fascia Latae</td>
<td>648</td>
<td>123</td>
</tr>
<tr>
<td>Gluteus Medius</td>
<td>650</td>
<td>147</td>
</tr>
<tr>
<td>Ipsilateral Multifidus</td>
<td>902</td>
<td>283</td>
</tr>
</tbody>
</table>
Intermuscular Timing

The 1-sample *t* test showed significant differences in mean relative latency times for 1 or more muscles during each movement task (*P*<.05). During PHE, the GMax was the only muscle activated significantly later than the CES, the first muscle to fire (*Figure 2*). Conversely, during SHA, all of the trunk muscles were activated significantly later than the first muscle to fire, the TFL (*Figure 3*). The TFL and GMed were activated before all of the trunk musculature. However, no significant difference in onset timing was identified between these two extremity muscles.

<table>
<thead>
<tr>
<th></th>
<th>Ipsilateral Erector Spinae</th>
<th>Contralateral Erector Spinae</th>
<th>Contralateral Multifidus</th>
<th>* Data are in millisecond (n=23)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>985</td>
<td>1003</td>
<td>1034</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>396</td>
<td>479</td>
<td>456</td>
<td></td>
</tr>
</tbody>
</table>

*FIGURE 2.* Activation timing of the contralateral multifidus (CMUL), biceps femoris (BF), semitendinosus (ST), ipsilateral multifidus (IMUL), ipsilateral erector spinae (IES), and gluteus maximus (GMax) relative to the timing of the contralateral erector spinae (0 line). * Indicates significant difference in muscle timing in relation to the contralateral erector spinae (*p*=0.004). Data in milliseconds (n=23).

*FIGURE 3.* Activation timing of the gluteus medius (GMed), ipsilateral multifidus (IMUL), ipsilateral erector spinae (IES), contralateral erector spinae (CES), and contralateral multifidus (CMUL) relative to the timing of the tensor fascia latae (0 line). * Indicates significant differences in muscle timing in relation to the gluteus medius (*p*=0.019). Data in milliseconds (n=23).
DISCUSSION

Understanding the normal muscle firing patterns during specific movement tasks can assist healthcare professions in identifying and treating musculoskeletal dysfunctions. The ability to clinically recognize these pattern deviations is critical to provide effective and efficient care. However, the research and clinical observations have provided inconsistent information concerning hip and trunk muscle firing patterns in healthy individuals (D’Orazio, 1993; Greenman, 2003; Lehman, et al., 2004; Pierce & Lee, 1990). Further, research has focused on the trunk and lower extremity activation levels during exercises/specific movements instead of the firing patterns (Bolgla & Uhl, 2005; Danneels, et al., 2002; Ekstrom, et al., 2007; Ekstrom, Osborn, & Hauer, 2008; Pitcher, et al., 2008). As more information is needed on muscle timing, this study investigated the firing patterns associated with two common lower extremity screening tasks (PHE and SHA) in healthy, pain-free adults.

The results of this study support the hypothesis that proximal musculature is activated first in order to create the stability needed to move the limb. During PHE, trunk and pelvic stabilization seems to be required in order to effectively mobilize the lower extremity. The gross recruitment pattern was identified and began with the contralateral trunk extensors, followed by the ipsilateral trunk extensors, and finally the GMax. The immediate activation of the contralateral trunk muscles may have been required to initiate the stabilization process and counter balance the force of the opposing limb. The stabilization cascade occurred very rapidly and the only muscle to significantly lag behind the process, possibly due to its primary role of producing torque on the limb, was the GMax. This study clearly refutes prior literature concerning the PHE movement task. Instead of firing early in the sequence, the GMax was found to fire last.

In contrast, the SHA movement task identified a pattern in which the distal musculature was recruited prior to the proximal stabilizers (trunk muscles). The gross pattern of muscle activation began with the GMed, followed by the ipsilateral trunk extensors, and finally the contralateral trunk extensors. For this task, the intermuscular timing analysis showed that all proximal musculature was recruited significantly later than the primary muscles responsible for limb motion (GMed and TFL). The position in which the task was performed, sidelying, may have provided increased pelvic stability and reduced the need for rapid trunk muscle recruitment. A study by Cynn et al., (2006) found that exercises with pelvic stabilization, such as the SHA, produced an increase in GMed muscle activation levels as compared with exercises without pelvic stabilization. The stable position allowed the muscle to function more effectively and, according to our results, fire earlier in the activation sequence.

CONCLUSION

Our study examined the muscle firing patterns during two common movement tasks in healthy, active, pain-free individuals. Future EMG research should examine if differences in muscle firing patterns exist between males and females. Arokoski et al., (2001) found that during certain movement tasks, EMG signal amplitude levels were consistently higher in the lumbar multifidus in women as compared to men. Similarly, Cynn et al., (2006) found that during SHA, EMG activity of the GMed and external oblique were significantly higher in women. Also, as differences in muscle firing patterns have been linked to LBP (Danneels, et al., 2002), future research is needed to examine trunk and hip muscle recruitment patterns during the same movement tasks in subjects with LBP.

Understanding the firing patterns for routine movement tasks can assist healthcare providers in properly screening patients with lower quarter dysfunctions. The results of this study suggest that the stability of the pelvis should be considered when performing common screening tasks such as the PHE and SHA. Lower extremity muscles were recruited earlier when the pelvis was in a position of stability (SHA). In contrast, the trunk muscles were activated first when the pelvis was not stabilized (PHE). The results of our research with the PHE task refute prior literature that the GMax should fire early in the sequence (Greenman, 2003). Instead of being dysfunctional, we found the normal recruitment pattern for PHE was for this muscle to be activated last in the sequence. Clinicians should consider this information and place more emphasis on visual inspection and palpation of the muscle contraction as opposed to an early activation.


