Hip- and Trunk-Muscle Activation Patterns During Perturbed Gait

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Context: Selected muscles in the kinetic chain may help explain the body’s ability to avert injury during unexpected perturbation. Objective: To determine the activation of the ipsilateral rectus femoris (RF), gluteus maximus (MA), gluteus medius (ME), and contralateral external obliques (EO) during normal and perturbed gait. Design: Single-factor, repeated measures. Setting: University research laboratory. Participants: 32 physically active, college-age subjects. Intervention: Subjects walked a total of 20 trials the length of a 6.1-m custom runway capable of releasing either side into 30° of unexpected inversion. During 5 trials, the platform released into inversion. Main Outcome Measures: Average, peak, and time to peak EMG were analyzed across the 4 muscles, and comparisons were made between the walking trials and perturbed trials. Results: Significantly higher average and peak muscle activity were noted for the perturbed condition for RF, MA, and EO. Time to peak muscle activity was faster during the perturbed condition for the EO. Conclusion: Rapid contractions of selected postural muscles in the kinetic chain help explain the body’s reaction to unexpected perturbation.

Keywords: ankle, dynamic stabilization, electromyography, inversion

The most common injury sustained by athletes is the inversion ankle sprain, which results in tearing of 1 or more lateral ankle ligaments.1 The ligaments are torn when the motion of the ankle exceeds an angle of approximately 40° of inversion.2 These ligaments are assisted in the role of stabilizing the ankle by the muscles of the lower leg. When unexpected ankle motion is detected, the muscles reflexively contract to slow or counteract the motion. However, after the time it took for the muscles to generate sufficient force was taken into consideration, the timing of the contraction was not found to be rapid enough to prevent the injury.3–6

Although the response of muscles near the ankle has been studied heavily, fewer studies on the role of muscles in the proximal kinetic chain have been conducted. Previous authors have demonstrated the importance of hip-muscle activation in maintaining control at the ankle.7–10 Those previous investigations help us understand the relationship between muscles throughout the kinetic chain and ankle pathologies. During gait, foot placement at heel strike may be affected because of

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the contraction of the hip abductors or adductors during the swing phase.\textsuperscript{7} A previous study determined that hip-abductor, -adductor, and -flexor strength were not significant predictors of ankle sprains\textsuperscript{10}, but other investigators found hip-abductor weakness after an individual suffered an inversion sprain.\textsuperscript{9,11}

To our knowledge, the only previous study to examine hip-muscle response to ankle inversion was conducted by Beckman and Buchanan.\textsuperscript{8} They measured the onset latency of the gluteus medius and peroneal muscles in subjects with hypermobile and normal ankles during a standing unexpected perturbation. Results showed significantly shorter gluteus medius onsets on both the ipsilateral and contralateral hips for the hypermobile group. Although that investigation helped explain the role of the hip musculature to an inversion moment, it failed to take into account the dynamic nature of athletics. Because the study was performed with the subjects stationary, important factors related to walking and running were omitted.

Previous research on human gait found that muscle contractions in the lower leg occur in anticipation of foot contact.\textsuperscript{12} These contractions help stabilize the foot-and-ankle complex and may affect the reaction times to unexpected inversion during activity.\textsuperscript{12} Hopkins et al\textsuperscript{13} examined the muscle-activation patterns during sudden ankle inversion in a stationary, standing position and during active gait. Their results showed significantly shorter reaction times of the tibialis anterior and peroneal muscles during the walking condition and higher peak and average EMG activity. Although those results have helped explain the dynamic response centered around the ankle, other models suggest that muscles higher in the kinetic chain are also involved.\textsuperscript{6} The premise that a reflexive response involves muscle actions beyond those of the lower leg supports the need for additional research to investigate this response. This knowledge of the role that the hip muscles play during unexpected inversion of the ankle while walking will support efforts to develop improved preventive and rehabilitative programs for the ankle.

**Purpose**

The purpose of this investigation was to determine hip- and trunk-muscle activation during normal gait and gait during an unexpected perturbation. Specifically, the study had 3 primary objectives: to measure muscle activity during normal walking gait, measure muscle activity during unexpected inversion of the dominant ankle, and compare the amplitude of muscle activity between normal walking gait and the unexpected-inversion trials.

**Methods**

**Subjects**

Thirty-two (14 male, 18 female) healthy college-age (20 ± 1.2 y) participants volunteered for the study. All were physically active as defined by participating in a minimum of 20 minutes of exercise at least 3 times per week. The mean weight and height of participants were 71.9 ± 12.4 kg and 173.0 ± 9.2 cm, respectively. Before data collection, all participants were screened via a questionnaire for a history of lower extremity injury in the past 6 months, and those indicating an injury
were excluded from the study. All participants signed the informed-consent form that had been reviewed and approved by the university institutional review board, which also approved the methods for the investigation.

**Instrumentation**

Muscle-activity measurements were collected using surface electromyography (MP100, BIOPAC Systems Inc, Santa Barbara, CA). Signals were amplified (DA100Bor TEL100M, BIOPAC Systems Inc) from disposable pregelled Ag–AgCl electrodes with a circular contact area of 1-cm diameter on a 41-mm-diameter moisture-resistant backing. The input impedance of the amplifier was 1.0 MΩ, with a common-mode rejection ratio of 90 dB; high- and low-pass filters of 20 and 400 Hz, respectively; a signal-to-noise ratio of 70 dB; and a gain of 1000. Electromyographic data were collected at a frequency of 1000 Hz per channel using Acknowledge 3.73 software (BIOPAC Systems Inc).

The custom-made runway (Figure 1) is 6.10 m in length, 0.25 m tall, and 0.76 m wide. It is divided into 5 1.22-m segments that can be rearranged and linked by clips located on the sides. One of the 5 segments includes a control panel to control another segment that has the ability to drop into 30° of inversion on either the right or left side when contact pressure is applied (Figure 2). When the mechanical lever

*Figure 1* — Custom-made runway.
removes the vertical support, the door rests on spring-ball plungers for support until pressure is applied to the trapdoor. When the force applied to the trapdoor exceeds 0.45 kg, the door drops, rotating about the center hinge into 30° of inversion. Two adhesive, nonslip strips mark the foot path to ensure appropriate foot placement and to prevent the foot from slipping when the trapdoor falls. No resistance, other than minimal friction from the hinge, affected the fall of the trapdoor. Handrails are built into the runway to provide support should a participant lose his or her balance. Electromagnetic switches on the platform trapdoors output a signal sampled with the EMG data to mark the trapdoor release for subsequent analysis.

**Protocol**

Data were collected from each participant’s dominant leg using surface EMG. For the purposes of our study, the dominant leg was defined as the leg the subject would strike with when kicking a ball. The skin underlying the electrodes was shaved, abraded with 220-grit sandpaper, and degreased with 70% alcohol to minimize electrical resistance. Electrodes were placed on each subject once, and all data collection was completed during that session.

Electrodes were placed over the ipsilateral rectus femoris (RF), gluteus maximus (MA), gluteus medius (ME), and contralateral external abdominal obliques (EO). All electrodes were placed 2 cm center to center in line with the respective muscle fibers following the recommendations of Winter. Placements for the electrodes were as follows: RF, midway between the anterosuperior iliac spine and the superior border of the patella; MA, over the area of greatest muscle bulk proximal to the line between the greater trochanter and ischial tuberosity; ME, approximately 3 cm below the midpoint of the iliac crest; and EO, midway between the lower costal margin and the midpoint of the iliac crest. A ground-reference electrode was placed
over the ipsilateral anterosuperior iliac spine. Care was taken to ensure that the electrodes were secured to the skin and movement artifact from clothing minimized.

After electrode placement, the subjects put on goggles that prevented them from seeing their inferior field of vision and were asked to walk down the runway to the beat of a metronome set at 90 beats/min. Subjects were instructed to walk normally toward a sign at the end of the runway that helped guide them in walking straight and also indicated the end of the runway. Each subject was asked to walk the length of the runway a total of 20 trials, with 5 trials being recorded with no runway perturbation and 5 trials with runway perturbation. Before the trials with perturbation, visual inspection confirmed that the subject would consistently step on the runway segment containing the trapdoor mechanism. The 5 trials with runway perturbation were recorded at random during the 15 trials to determine muscle activity during the unexpected inversion. After each trial, visual inspection of the raw EMG was conducted to ensure that the data were “clean,” meaning that the subject did not anticipate the platform drop. The additional trials helped improve randomization of the normal versus perturbed gait. To help determine the moment of foot contact, a switch connected to the EMG signal was triggered during each heel strike for the dominant leg during the nonperturbed gait.

**Data Processing**

EMG data were exported for processing with custom software. For each trial, data from each muscle were converted to linear envelopes by zeroing to the baseline, rectifying the signal, and low-pass filtering (Butterworth) with a cutoff set at 4 Hz. Trapdoor release was identified from the appropriate data channel, and muscle onset was defined as an EMG level 2 SDs above the mean value of the EMG over the 150 ms before the trapdoor falling or before the current generated by the switch at heel strike for the nonperturbed gait. The average and peak EMG values were calculated from the 200-millisecond interval after muscle onset.

**Statistical Analysis**

A 1-way between-groups multivariate ANOVA (SPSS version 15.0, SPSS Inc, Chicago IL) was used to determine significant differences between the normalized trials and the unexpected perturbation. The independent variable was task (normal gait vs perturbed gait), and the dependent variables were average EMG of the muscle contraction, peak EMG of the muscle contraction, and time to peak muscle contraction. Before statistical analyses several assumptions were tested. The Levene test of equality of variances showed a violation among numerous dependent variables. Based on this violation, the alpha level was dropped to .025. After the Bonferroni correction, the alpha level for all statistical tests was set at .002.

**Results**

There was a statistically significant difference between the 2 conditions on the combined dependent variables ($F_{12,51} = 7.10$, $P = .001$, Wilks’s $\Lambda = 0.37$, partial eta squared = 0.63). Results from the MANOVA table are presented in Table 1. When the results of the dependent variables were considered separately, significant
differences for average muscle activity were found for the RF, MA, and EO muscles, with greater muscle activity occurring during the perturbed condition. Peak muscle activity was found to be significantly greater for the RF, MA, and EO during perturbed gait. Time to peak muscle activity was significantly different for the ME, MA, and EO. Analysis revealed significantly faster time to peak muscle activity for the EO but significantly slower time to peak for the ME and MA. Descriptive statistics (means and standard deviations) for each dependent variable across the 2 conditions are presented in Table 2.

Table 1  Results From the MANOVA Table

<table>
<thead>
<tr>
<th>Measure</th>
<th>Muscle</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
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<tbody>
<tr>
<td>Average EMG</td>
<td>rectus femoris</td>
<td>0.23</td>
<td>1</td>
<td>0.23</td>
<td>27.00</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>gluteus maximus</td>
<td>0.28</td>
<td>1</td>
<td>0.28</td>
<td>17.46</td>
<td>.001</td>
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<tr>
<td></td>
<td>gluteus medius</td>
<td>0.18</td>
<td>1</td>
<td>0.18</td>
<td>8.14</td>
<td>.006</td>
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<tr>
<td></td>
<td>external oblique</td>
<td>0.37</td>
<td>1</td>
<td>0.37</td>
<td>27.19</td>
<td>.001</td>
</tr>
<tr>
<td>Peak EMG</td>
<td>rectus femoris</td>
<td>1.09</td>
<td>1</td>
<td>1.09</td>
<td>18.73</td>
<td>.001</td>
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<tr>
<td></td>
<td>gluteus maximus</td>
<td>1.38</td>
<td>1</td>
<td>1.38</td>
<td>12.75</td>
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<tr>
<td></td>
<td>gluteus medius</td>
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<td>1</td>
<td>0.75</td>
<td>8.78</td>
<td>.004</td>
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<tr>
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<td>external oblique</td>
<td>2.58</td>
<td>1</td>
<td>2.58</td>
<td>23.56</td>
<td>.001</td>
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<tr>
<td>Time to peak EMG</td>
<td>rectus femoris</td>
<td>0.00</td>
<td>1</td>
<td>0.00</td>
<td>0.07</td>
<td>.794</td>
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<td>1</td>
<td>0.49</td>
<td>17.49</td>
<td>.001</td>
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<tr>
<td></td>
<td>gluteus medius</td>
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<td>1</td>
<td>0.04</td>
<td>20.11</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>external oblique</td>
<td>0.04</td>
<td>1</td>
<td>0.04</td>
<td>27.21</td>
<td>.001</td>
</tr>
</tbody>
</table>

SS, sum of squares; MS, mean squares.

Table 2  EMG Data During Normal and Perturbed Gait

<table>
<thead>
<tr>
<th>Measure</th>
<th>Muscle</th>
<th>Normal Gait</th>
<th>Perturbed Gait</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Average EMG (mV)</td>
<td>rectus femoris</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>gluteus maximus</td>
<td>0.10</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>gluteus medius</td>
<td>0.13</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>external oblique</td>
<td>0.08</td>
<td>0.04</td>
</tr>
<tr>
<td>Peak EMG (mV)</td>
<td>rectus femoris</td>
<td>0.14</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>gluteus maximus</td>
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<td>0.12</td>
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<tr>
<td></td>
<td>gluteus medius</td>
<td>0.22</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>external oblique</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>Time to peak EMG</td>
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<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
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<td>gluteus maximus</td>
<td>0.10</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>gluteus medius</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>external oblique</td>
<td>0.18</td>
<td>0.04</td>
</tr>
</tbody>
</table>

* P < .002.
Discussion

Previous studies have looked at the role of the hip musculature as a risk factor for preventing injury, hip strength after an ankle injury, and hip-muscle EMG onset latency. However, those studies examined hip-muscle activity during a static (standing) activity. The purpose of this study was to understand the dynamic response of selected hip muscles during unexpected perturbation while walking. The instrument used in this study permits the findings to be more generalized to athletics because of the dynamic activation of the muscles during walking as opposed to during static stance. Results showed greater average and peak muscle activity during perturbed gait than with normal walking. In addition, significantly faster time to peak muscle activity was found in the EO during the perturbed condition.

Research on postural control has offered insight into the risk factors for sustaining an ankle sprain. McKeon and Hertel performed a systematic review and found poor postural control to be a risk factor for sustaining an inversion ankle sprain. After injury to the static structures of the lower leg, dynamic postural stability of the hip and pelvis decreases. Those findings were confirmed through the systematic review, but the evidence on postural control was inconclusive for whether there are within-subject differences between the injured and noninjured limb. Further research has shown that individuals with chronic ankle instability demonstrate altered motor-control mechanisms, suggesting the body’s attempt to reduce the postural demands of the affected limb.

The results from previous studies have shown the importance of understanding the muscle-activation patterns of the proximal kinetic chain during unexpected inversion. During unexpected perturbation, the body responds and makes corrections in response to loss of balance through an ankle strategy, hip strategy, or a combination of the two. The ankle strategy is responsible for making small adjustments in postural sway to restore equilibrium, whereas the hip strategy uses the trunk and thigh muscles to respond and correct for larger perturbations occurring in the body. During ankle inversion, the ankle strategy is insufficient and the hip strategy is recruited to correct the lateral sway occurring in the body. Previous research found that these responses to perturbations began in the ankle and radiated in sequence up the kinetic chain to the thigh and trunk muscles, demonstrating a predictable sequence in an attempt to maintain balance.

The results from our study confirmed the activation of the thigh and trunk muscles through an increase in the average and peak EMG during the perturbed gait. Although these results suggest the use of the hip strategy, the timing of the activation must be considered. Our results showed an increase in peak and average EMG of the RF, MA, and EO; however, the timing of the MA and ME showed they took significantly longer to reach their peak activity. Konradsen and Ravn showed a pattern of hip and knee flexion, along with contraction of the peroneals, during unexpected inversion. According to that research, the body attempts to avert further injury by removing the weight from the inverting limb through flexion at the ipsilateral hip and knee. The delayed reaction seen in our study of the MA, as a hip extensor, would be in agreement with Konradsen and Ravn’s assessment. In contrast, an increase in the peak and decrease in time to peak activity of the opposite
EO would suggest the body’s attempt to maintain equilibrium by transferring the center of gravity from the involved to the uninvolved limb. Our study also saw a delay in the activation of the ME during perturbed gait. Beckman and Buchanann had similar findings when looking at the contralateral ME during inversion. Their results showed a predictable sequence of contralateral ME activation occurring first, followed by ipsilateral ME contraction. They attributed these findings to a polysynaptic reflex generated in the ankle mechanoreceptors and not a result of the stretch reflex.8

The sequence of muscle activity found in our study may help to further explain how the body attempts to avert further injury by limiting additional pressure being placed on the involved limb, thus possibly protecting the lateral ligaments of the ankle. Our results are in agreement with previous findings on the role of the hip musculature during an inversion moment and suggest that during gait, the timing of muscles in the hip and pelvis play a role in stabilizing the body in an attempt to reduce further injury to the lateral ankle ligaments.

There were a few limitations inherent to this study that should be mentioned. First, because of limitations of the EMG telemetry unit, we were unable to compare the muscle activity bilaterally during the 2 conditions. Studying both sides would have helped us better understand the role of the contralateral hip muscles in stabilizing the trunk. Furthermore, it would have been beneficial to study the hip and knee flexors to determine whether the time to peak muscle activity differed between the perturbed and unperturbed conditions. Next, we only instrumented the dominant leg, making somewhat apparent to the subject the side that would be inverted. Although we randomized the perturbation process through multiple walking trials, the subjects did know the trapdoor could potentially fall on any trial. This could have been eliminated by applying electrodes to both legs while only collecting data from the dominant leg. Furthermore, this study did not measure the inversion at the ankle during the unexpected perturbation. Although the dynamic response of these muscles has been studied, their role in decreasing the inversion moment at the ankle is still unknown. Finally, the standard deviations for the perturbed conditions were higher than in the nonperturbed condition. This difference in variance could be a result of error associated with EMG as the electrodes and underlying skin slide on the muscles during dynamic activity or could suggest the possibility that each individual responds in a somewhat unique fashion to the unexpected perturbation. The postural variations (trunk lean, center of gravity), proprioceptive variations, and dynamic response to the perturbation of the individual participants could yield increased variability between the participants.

Conclusions

In conclusion, we found significantly higher average and peak EMG for the RF, MA, ME, and EO during the perturbed than unperturbed gait. Time to peak EMG was significantly faster during the perturbed condition for the EO but significantly slower for the MA and ME. These results suggest that the body’s neuromuscular system uses contractions of selected postural muscles to help prevent or reduce the severity of unexpected ankle inversion.
References